Regrowth of *Festuca hallii* (Vasey Piper) and *Stipa curtiseta* [(A.S. Hitch.) Barkworth] following defoliation on a hummocky landscape in central Saskatchewan

A Thesis Submitted to the College of Graduate Studies and Research in Partial Fulfillment of the Requirements For the Degree of Master of Science in the Department of Plant Sciences University of Saskatchewan Saskatoon

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Abstract

A 4-year study was conducted on the Missouri Coteau in the Mixed Grassland Ecoregion of Saskatchewan to determine the effects of mowing to a 7.5 cm stubble height on the growth of *Festuca hallii* (Vasey) Piper and *Stipa curtiseta* (A.S. Hitch.) Barkworth. Green standing crop (GSC), dead standing crop (DSC) and above ground net primary production (ANPP) were compared to an unmowed control after a single mowing in April, May, June, July, August, September, October or November on 5 landforms including north aspect-concave-slope, north aspect-convex-slope, south aspect-concave-slope, south aspect-convex-slope and level upland. Mowing reduced GSC, DSC and ANPP with reductions varying among months of mowing and among landforms. Green standing crop, DSC and ANPP of *F. hallii* were greatest on the north aspects and least on south aspect-convex slope and ranged from 2 to 122 g m^{-2}, 3 to 121 g m^{-2}, and 8 to 122 g m^{-2}, respectively. Mowing reduced GSC of *F. hallii* for 1 to 11 growing season months and DSC for 1 to >11 growing season months. Mowing in May or November reduced ANPP of *F. hallii* for 1 growing season, while mowing in other months reduced ANPP for 2 growing seasons. Green standing crop of *S. curtiseta,* ranging from 3 g m^{-2} to 55 g m^{-2}, was least on the north aspects and greatest on the south aspect-convex slope and was reduced 1 to 5 growing season months following mowing. Mowing after June reduced DSC of *S. curtiseta* (5 to 58 g m^{-2}) for 1 to 10 growing season months, and ANPP (6 to 64 g m^{-2}) for 1 growing season. Generally, mowing reduced GSC, DSC and ANPP of *F. hallii* longer than *S. curtiseta.* Production of *F. hallii*- and *S. curtiseta*-dominated plant communities in the Northern Mixed Prairie will be maintained by providing rest periods between defoliation events based on the number of growing season months for *F. hallii* to recover production.

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Dedication

[I would like to dedicate this thesis to Dad and Grandpa. They introduced me to natural ecosystems and encouraged me to explore.]

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

Grazing is the dominant use of the Northern Mixed Prairie in Saskatchewan (Abouguendia 1990, PCAP 2003). The insight that the Northern Mixed Prairie evolved with grazing (Mack and Thompson 1982, Hartnett et al. 1996) is of limited value if grazing practices lead to undesirable changes in the structure, composition, and functioning of native rangelands (Fleischner 1994). A common goal of grazing management is to prevent overgrazing. Preventing overgrazing requires that plants are rested after grazing. Co-evolution of native grasses, native ungulates and grazing patterns allowed rest between grazing events (Hartnett et al. 1996), and overgrazing occurs when plants are not given adequate time to recover following defoliation (Kowalenko and Romo 1998). Plants of the Northern Mixed Prairie regrow at different rates following defoliation (Trlica et al. 1977, Zhang and Romo 1994, Kowalenko and Romo 1998). Plants require time between defoliation events to regrow, to maximize production and to maintain their position in the plant community (Caldwell 1984). The time needed by plants after grazing must be understood if the structure, composition and functioning of the Northern Mixed Prairie are to be maintained.

Less than18% of the Mixed Grass Prairie remains in its natural state in Saskatchewan (Pylypec and Romo 2003). Prairie ecosystems provide a variety of amenities including forage, intrinsic value, wildlife habitat, biodiversity and recreation (West 1993, PCAP 2003). Prairie landscapes are important habitats for flora and fauna that requires the diverse structure and function native landscapes offer (Trlica et al. 1977, Moore 1999, PCAP 2003). Although the dominant use of remnant native grassland is grazing, management of the Mixed Grass Prairie should consider all uses.

Native grasses of the Northern Mixed Prairie are nutritional and an inexpensive source of forage when managed properly (Willms and Jefferson 1993). Landscapes composed of rolling terrain are often spared of cultivation in the Northern Mixed Prairie (Barnes et al. 1983) and there is a need for management recommendations for these prairie remnants. Identifying the characteristics of ecosystems and their components and how management practices affect them is key to sustainable use (Willms and Jefferson 1993).

Variation in slope position and slope aspect create differences in microclimate that in turn influence plant community composition and production (Ayyad and Dix 1964, Baines 1973, Leifers and Larkin-Leifers 1987). Northerly aspects tend to be cooler and moister, while southerly aspects and level uplands have intermediate soil temperatures and soil water (Ayyad and Dix 1964, Braun 2005). *Festuca hallii* (Vasey Piper) and *Stipa curtiseta* [(A.S. Hitch.) Barkworth] dominate some plant communities in the Northern Mixed Prairie depending on slope position, slope shape and slope aspect (Ayyad and Dix 1964, Baines 1973).

Grazing alters plant vigor, production and abundance (Jameson 1963, Caldwell 1984). The time required by plants to completely regrow after grazing is influenced by the time of grazing (Pearson 1964). Plants of the Northern Mixed Prairie are believed to regrow more quickly when defoliated in late summer or while dormant than if defoliated during the growing season (Zhang and Romo 1994, Brown 1995, Cullen et al. 1999). Information on the seasonal affects of defoliation is needed to maintain the production of native plants.

The objective of this study was to determine how long above ground production of *S. curtiseta* and *F. hallii* is reduced following mowing in 8 different months within 5 landforms in the Northern Mixed Prairie of central Saskatchewan. *Festuca hallii* and *S. curtiseta* were chosen for study because these native grasses are productive, sensitive to grazing, and our knowledge of them can be expanded.

The hypotheses tested were: 1) green standing crop, dead standing crop and above ground net primary production (ANPP) of *F. hallii* and *S. curtiseta* are similar to that in an unmowed control following mowing in 8 different months; 2) green standing crop, dead standing crop and ANPP of *F. hallii* and *S. curtiseta* are similar among landforms; 3) soil water content is similar to the unmowed control following mowing in 8 different months, and; 4) soil water content is similar among landforms.

2.0 LITERATURE REVIEW

2.1 Ecology of the Northern Mixed Prairie

The Northern Great Plains of North America encompasses 24 million ha in Canada, of which 6.5 million ha remain as native prairie (Willms and Jefferson 1993). The Mixed Prairie extends 2,400 km from Canada to northern Texas (Coupland 1961) and the Mixed Grass Prairie Ecozone coincides with the Brown and Dark Brown soil zones of Saskatchewan (Coupland 1961). The climate of the Northern Mixed Prairie of Saskatchewan is semiarid and characterized by long, cold winters and short, hot summers (Coupland 1950). Annual precipitation ranges from 280 mm in the Brown soil zone to 450 mm in the Dark Brown soil zone (Coupland 1961). Most precipitation is received from May through July (Peltzer and Kochy 2001, Colberg and Romo 2003).

Plant community structure, composition and functioning change with environmental conditions (Coupland 1958), topography (Ayyad and Dix 1964, Leifers and Larkin-Leifers 1987) and management (Fuhlendorf and Engle 2001) in the Northern Mixed Prairie. Different plant communities arise from variation in soil water content (Redmann 1975, Leifers and Larkin-Leifers 1987, Knapp et al. 1993), microclimate (Ayyad and Dix 1964), soil type and soil fertility (Haase and Schreiber 1972) created by differences in slope position and slope aspect. Varying locations on slopes have different temperatures, intensity of solar radiation (Williams 1974) and wind speed (Cantlon 1953, Leifers and Larkin-Leifers 1987).

Festuca hallii and *Stipa curtiseta* are common native grasses in the Northern Mixed Prairie of central Saskatchewan (Ayyad and Dix 1964). The abundance of these perennial grasses varies with slope aspect (Ayyad and Dix 1964), soil water content, management and climate (Coupland 1961). *Festuca hallii* grows on sites that are relatively cool and moist whereas *S. curtiseta* dominates relatively warm and dry sites (Moss 1955). *Festuca hallii*-dominated communities are present at higher elevations and on north aspects (Coupland 1961, Ayyad and Dix 1964, Stout et al. 1981). *Stipa curtiseta* tends to be most abundant on east- and south-facing slopes (Ayyad and Dix 1964), and this grass co-dominates with *Agropyron dasystachyum* [(Hook.) Scribn.] on sites with intermediate amounts of soil water (Coupland 1961).

2.2 Topography and Landscape Pattern

Topography contributes to the variability of plant communities on landscapes with similar climate and management (Fuhlendorf and Smeins 1998). Topography has significant influences on vegetation (Ayyad and Dix 1964) and soil characteristics in the Northern Mixed Prairie of Saskatchewan (Pennock et al. 1987). Variation in slope aspect, slope position and slope shape all create localized differences in temperature, wind velocity, solar radiation and soil water content (Cantlon 1953, Ayyad and Dix 1964, Whitman 1974, Radcliffe and Lefever 1981, Braun 2005). South- and west-facing slopes are generally exposed to greater wind velocity and they receive more solar radiation than north-facing slopes (Ayyad and Dix 1964). North- and east-facing slopes are therefore expected to have more soil water than south- and west-facing slopes. More soil water improves conditions for plant growth and soil development (Cosby 1964). The soil water regime on hummocky landscapes is controlled by slope shape, slope aspect, slope position and the influence of these factors on evaporation, water runoff, and water collection (Leifers and Larkin-Leifers 1987). South aspects and convex-shaped slopes tend to be drier than north aspects and concave-shaped slopes (Pahlsson

1974, Leifers and Larkin-Leifers 1987). A gradient in available soil water exists from uplands to lowlands, and thus plant productivity is related to slope position (Knapp et al. 1993, Singh et al. 1998). Similarly, slope plan curvature should reflect a gradient in resources from convex- to concave-shaped landforms.

Landscapes are composed of landforms (Pennock et al. 1987) or ecological patches (Swanson et al. 1988). Landforms are useful in compartmentalizing and analyzing abiotic and biotic processes on landscapes (Swanson et al. 1988). Hummocky landscapes have numerous slope characteristics that can be segmented into different landforms (Pennock et al. 1987). Landforms distinguished in central Saskatchewan are divergent shoulders, convergent shoulders, divergent backslopes, convergent backslopes, divergent footslopes, convergent footslopes and depressions (Pennock et al. 1987). Convergent landforms appear concave in shape and divergent landforms appear convex-shaped. Shoulder slopes are at the top of hills, backslopes characterize mid-slopes and footslopes are located at the bottom of slopes.

Landforms can differ in elevation, aspect, parent material and slope. Air temperatures, soil temperatures and quantities of soil water and soil nutrients can vary among landforms (Swanson et al. 1988). Topographic gradients induce changes in the composition of plant communities and ecosystem functioning (Vinton and Collins 1997). Landforms control water movement on landscapes (Pennock et al. 1994) and they affect the flow of organisms, energy and soil material (Swanson et al. 1988). Water movement influences plant growth, erosion and nutrient concentrations at various slope positions (Leifers and Larkin-Leifers 1987). The specific catchment area and specific dispersal area are terrain attributes describing water distribution on a landscape (Bedard-

Haughn and Pennock 2002). Specific catchment area is the upslope area that drains into landforms while specific dispersal area is the down slope area of the landform into which water drains. Lower slope positions and concave-shaped landforms tend to have larger catchment areas than upper slopes and convex-shaped landforms (Bedard-Haughn and Pennock 2002).

The physical characteristics of soil tend to vary with slope position, slope aspect, and slope shape (Pennock et al. 1987). Soils on south aspects and upper slope positions are generally coarser textured with less water holding capacity than soils on north aspects and lower slope positions (Ayyad and Dix 1964, Slobodian et al. 2002). Water transfers finer soil particles downslope and into convergent landforms (Wysocki et al. 2000). Deposition of finer particles increases the bulk density of soil, water retention, organic carbon and nutrient concentration of soils thereby creating soils with thicker A-horizons (Pennock et al. 1994, Slobodian et al. 2002). Landforms with thicker A horizons are typically more fertile (Slobodian et al. 2002). Total carbon and nitrogen, potential soil carbon, rates of nitrogen mineralization and soil respiration generally increase from upland landscape positions to lowlands and from convex- to concave-shaped slopes (Schimel et al. 1985).

The occurrence of different plant communities is controlled by biotic and abiotic conditions on a landscape. Precipitation and soil water control the distribution and abundance of plants (Barnes et al. 1983, Schulze et al. 1987). Different plant species composition among landforms indicates discrete growing conditions among landforms (Dix 1958, Barnes et al. 1983). Macro- and micro-environmental conditions on the landscape can be altered by grazing (Whitman 1974). Potential solar radiation is less on northerly aspects than on southerly aspects and uplands (McCune and Keon 2002, Braun 2005). Greater solar radiation on southerly aspects increases temperatures and evaporation, creating a drier environment than north-facing aspects (Cantlon 1953).

Festuca hallii and *S. curtiseta* are good indicators of changes in abiotic and biotic factors occurring on different slope aspects and slope positions in the Northern Mixed Grass Prairie (Ayyad and Dix 1964). *Festuca hallii* dominates northerly aspects, while *S. curtiseta* is more prevalent on southerly aspects and level uplands in central Saskatchewan (Ayyad and Dix 1964, Baines 1973). The prevalence of *F. hallii* on northerly aspects is attributed to a cool, moist, nutrient rich environment; by contrast, *S. curtiseta* occupies sites with intermediate temperatures, nutrients and soil water content (Coupland 1961, Ayyad and Dix 1964, Baines 1973).

2.3 Consequences of Defoliation on Plant Growth

Defoliation of plants increases, decreases or has no effect on plant production and plant community dynamics (Maschinski and Whitham 1989, Turner et al. 1993). Controversy exists over the responses of plants to defoliation (Painter and Belsky 1993). Plant responses to defoliation are related to the timing of defoliation, resource availability and competition (Maschinski and Whitham 1989). Increased photosynthetic rates, greater allocation of photosynthate to shoots, increased tillering, and reduced evapotranspiration following removal of above ground plant material may increase ANPP (Hilbert et al. 1981). However, a period that is conducive for growth of plants is required between defoliation events for green standing crop, dead standing crop and ANPP of plants to recover after grazing.

Defoliation intensity, duration, season, and history alter plant growth (Jameson 1963, Hyder 1972, Dahl and Hyder 1977, Caldwell 1984, Maschinski and Whitman 1989, Briske and Richards 1995). Defoliation and removal of litter affect plant growth by creating a lighter, drier, and warmer microenvironment than undisturbed plant communities (Whitman 1974, Willms et al. 1986, Ferraro and Oesterheld 2002). Plants require specific amounts of nutrients, light, water and temperatures for growth (Billings 1952). Regrowth of plants following defoliation affects their competitive ability and abundance in plant communities (Ferraro and Oesterheld 2002). Plant responses to defoliation are unique, and understanding these responses is essential for proper grazing management (Ellison 1960, White 1973).

Increased production by some plant species following defoliation has led to general statements that plant production increases after grazing in the Northern Mixed Prairie (Eneboe et al. 2002, Frank et al. 2002, Loeser et al. 2004) and specifically severe defoliation (Savory 1980). Some plants are relatively unaffected by defoliation in controlled experiments, but production by these same species is reduced by environmental constraints and competition in the field (Mueggler 1972). Desirable grasses generally decline in vigor and abundance if adequate time is not provided for growth between defoliation events (Buwai and Trlica 1977, Kowalenko and Romo 1998, Bai et al. 2001). Reduced abundance and vigor of desirable grasses after defoliation in turn reduces plant production in the Northern Mixed Prairie (Kowalenko and Romo 1998).

Plants can regain their vigor and competitive ability if an adequate amount of time elapses between defoliation events (Caldwell 1984). Removing leaf area from plants reduces photosynthesis and plants rely on current photosynthesis to resume growth following leaf removal (Richards and Caldwell 1985, Briske and Richards 1995). Plant vigor and growth are reduced the following growing season, or more, if plants cannot regrow before entering dormancy (Menke and Trlica 1981, Trlica 1999). Grasses that quickly allocate resources to shoot production following shoot removal are typically more tolerant of grazing (Menke and Trlica 1981) than species that allocate resources for maintenance and growth of roots (Richards and Caldwell 1985).

Soil water content influences plant growth after defoliation and it is the primary factor controlling plant production in the Northern Mixed Prairie (Wight and Black 1978, Newbauer et al. 1980, Looman 1980, Anderson and Holte 1981, Maschinski and Whitham 1989, Loeser et al. 2004). The influence of soil water content, nutrients and temperature on growth after defoliation varies among species of grasses. It is often assumed that grasses recover standing crop sooner following defoliation on wet sites than dry sites (Anderson and Holte 1981, Maschinski and Whitman 1989, Painter and Belsky 1993, Loeser et al. 2004). Adaptations to environmental conditions may also influence growth following defoliation. *Stipa thurberiana* (Piper) grew faster after defoliation under moist conditions than under dry conditions (Ganskopp 1998, Eckert and Spencer 1987). In contrast, clipping *Agropyron cristatum* [(L.) Gaertn.] reduced forage production by 50% in wet years, but reductions in forage production were not apparent in dry years (Miller et al. 1990). *Stipa comata* (Trin.&Rupr.) regrew faster following defoliation in a dry year than in a wet year (Pearson 1964). Differences in soil water content among landforms may lead to differences in growth of plants following herbage removal.

The stage of growth when plants are defoliated influences individual plant and plant community dynamics after defoliation (Pearson 1964, Maschinski and Whitham 1989). Plants are usually less affected by being defoliated when dormant compared to being defoliated when they are growing (Cullen et al. 1999). Grazing at times least detrimental to plants helps maintain vigor, production and species composition of plant communities (Caldwell 1984). Many plants of the Northern Mixed Prairie have the C_3 photosynthetic pathway and their photosynthesis peaks during June and July (Redmann 1975, Pearson 1979). Carbon reserves of C_3 grasses tend to be low during growth, and defoliation during peak photosynthesis reduces plant growth (Pearson 1979, Zhang and Romo 1994, Cullen et al. 1999). More *Festuca scabrella* (Torr.) was killed and the vigor of surviving plants was reduced more the next growing season when clipped in late May through June as compared to plants clipped in only May or in the fall (Mclean and Wikeem 1985). Greater plant survival was attributed to the remaining photosynthetic leaf surface when plants were not clipped while growing. Defoliating *F. hallii* in September is less detrimental to plant vigor and survival than if defoliated in other months (Horton 1991).

Stipa species respond in unique ways to different months of defoliation. *Stipa comata* is intolerant of herbage removal in June or July (Pearson 1964). Above ground standing crop of *S. comata* defoliated in September, October, or April was similar to the control the following year (Pearson 1964). Green standing crop, basal area, root mass, and height of *Stipa thurberiana* were reduced the year following a single defoliation in April through July (Eckert and Spencer 1987). Above ground standing crop of *S. thurberiana* was reduced less by defoliating early in the growing season as compared to defoliating later (Eckert and Spencer 1987). Clipping in May and early June reduced above ground standing crop of *S. comata* compared to an unclipped control while clipping in mid-June through July had no effect on above ground standing crop (Holderman and Goetz 1981). In another study, *S. comata* was most tolerant of clipping in May or June and least tolerant of clipping in July or August (Wright 1967). The variable responses of *S. comata* to defoliation are attributed to the ability of plants to photosynthesize throughout the growing season and to tolerate clipping when temperatures and soil water content are adequate for growth (Wright 1967).

Previous research emphasized that plant responses to defoliation are related to the time of defoliation (Smoliak 1960, Pearson 1964, Willms 1988a, Dormaar et al. 1989). Grasses typically require at least 1 growing season to regain production following defoliation in the Northern Mixed Prairie (Schellenberg et al. 1999). *Agropyron smithii* (Rydb.) regained vigour and yield within 14 to 26 months after being defoliated (Trlica et al. 1977). *Bouteloua gracilis* [(HBK) Lag.] grew more quickly when defoliated in November than if defoliated between April and November (Trilca et al. 1977). More than 2 growing seasons elapsed before ANPP, green standing crop, and dead standing crop of *A. dasystachyum* equalled an unmowed control in central Saskatchewan (Zhang and Romo 1994, Kowalenko and Romo 1998). Production of *A. dasystachyum* is reduced by defoliation during the growing season (Kowalenko and Romo 1998) because photosynthesis of the grass peaks in June and declines in the following months (Redmann 1978). Above ground net primary production and green standing crop are reduced for less time if grazing is deferred until after peak photosynthesis (Kowalenko and Romo 1998).

Plant regrowth may be a function of available soil water in combination with time of defoliation (Biondini et al. 1998). Dry matter yield of *F. hallii* was greater in months with high precipitation than if defoliated when precipitation was limited (Horton 1991). C_3 plants dominate the Northern Mixed Prairie and most growth occurs in May through to July when soil water is available (Coupland 1958, Barnes et al. 1983). Because soil water content and precipitation vary through time, season of defoliation is an important consideration in the Northern Mixed Prairie. Most precipitation is received in May and June (Colberg and Romo 2003) and summer precipitation is often limited and unpredictable. Soil water content is typically greater in the spring and less in the summer and fall (Sala and Laurenroth 1982). It is expected plants will regain green standing crop, dead standing crop and ANPP quicker if defoliated when dormant or when soil water is available.

3.0 EXPERIMENTAL APPROACH

Research was conducted in the Coteau Hills landscape of the Mixed Grassland Ecoregion of central Saskatchewan (Acton et al. 1998). The study site was located about 20 km south of Macrorie, Saskatchewan and the legal land description is SW ¼, Section 20, Township 26, Range 9, W 3rd meridian. The study site lies in the Dark Brown soil zone, and the soils are classified as Calcareous Dark Brown Chernozems of the Weyburn Association (Ellis et al. 1970). Temperatures for the area average 4˚C and range from monthly means of –14˚C in January to 19˚C in July (Table 3-1). Annual precipitation averages 367 mm, with 49% being received in May, June and July (Table 3-1).

Precipitation and temperature records were obtained from an Environment Canada weather station at Rocky Point, Saskatchewan about 10 km from the study site (Table 3-1). Annual precipitation received in 2001 through 2004 was 55%, 109%, 73% and 108%, respectively, of the long-term average. Annual temperatures in 2001 through 2004 were within 1ºC of the long-term average.

The study site is characterized as a knob-and-kettle terrain (Figure 1). Uplands are dominated by perennial, native grasses while lowlands are dominated by shrubs. Vegetation in depressions consists mainly of *Symphoricarpos occidentalis* (Hook.). Wetlands are ringed by *Salix* spp. and *Populus tremuloides* (Michx.), and these wetlands typically have standing water in May through to June. *Artemisia frigida* (Willd.) and *Rosa arkansana* (Porter) are common throughout the landscape.

Figure 1. Oblique aerial view of the study area. Some of the plots are visible near the center of the photograph.

Table 3-1. Total monthly precipitation, average monthly temperature during the study and long-term average precipitation and temperatures (1974-2004) at Rock Point, Saskatchewan.

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
	Temperature (ºC)												
2000	-15	-8	0	5	11	14	19	18	13	6	-5	-17	4
2001	-6	-15	-1	6	13	16	20	21	14	4	0	-10	5
2002	-11	-5	-13	0	9	17	20	17	12	0	-3	-5	3
2003	-13	-14	-6	5	12	16	20	22	12	9	-9	-7	4
2004	-16	-8	-1	6	8	13	18	15	12	4	-1	-9	4
Long-term average	-14	-10	-4	5	11	16	19	18	12	5	-5	-11	4
	Precipitation (mm)												
2000	18	2	10	41	22	93	94	38	54	11	20	28	432
2001	6	10	3	4	34	29	74	1	9	8	11	10	201
2002	12	3	14	9	7	130	45	85	45	22	12	16	400
2003	21	25	3	52	24	38	33	7	33	21	6	5	268
2004	11	5	7	8	51	74	59	106	28	24	1	26	399
Long-term average	16	10	17	22	51	69	60	36	30	19	16	20	367

A randomized-complete-block design with 8 replicates of 5 different landforms and 9 mowing treatments was used in this study. Four replicates were started in 2001-2002 and 4 more replicates were started in 2002-2003. Catenas were selected as replicates and each catena was divided into northerly and southerly aspects; the landforms were chosen according to slope shape and slope aspect. Except for the level upland landform, all landforms were at the backslope position (Pennock et al. 1987). The landforms included the level upland, north aspect-concave-shaped slope, north aspect-convex-shaped slope, south aspect-concave-shaped slope, and south aspect-convex-shaped slope.

An 18- by 20 m block was established on each replicate landform and the block was separated into 9, 2- by 20 m plots that were oriented from the top to the bottom of the slope. The 9 mowing treatments, including an unmowed control, were randomly assigned to plots and the plots were mowed once with a Jari sickle mower to a height of 7.5 cm. Mowing to a height of 7.5 cm was intended to represent the intensity of grazing that is common on rangelands in this area. All mowed plant material was removed from the plots. Four replicate plots were mowed once in mid-May through mid-November 2001 and mid-April 2002. Another set of 4 replicates was mowed in 2002-2003 in the same months.

Each plot was subdivided into 4 sections that were 5 m long, and 1, 50 by 50 cm quadrat was randomly located within each section of the plot and clipped to ground level to determine the amount of standing crop remaining after mowing. Mowing removed 67 to 84% of green standing crop, and averaged 76% in May, 78% in June and July and 79% in August (Table 3-2). Standing crop of plants following mowing was determined by clipping plants at ground level in 1, 50 by 50 cm quadrat that was randomly located in each of the 4, 5 m sections of replicate plots. Standing crop was determined in 4 replicates established in 2001-2002 by clipping at ground level in June, July and August 2001, June, July and August 2002, and June and July 2003. Standing crop was determined in 4 replicates started in 2002-2003 by clipping at ground level in June, July and August 2002, June, July and August 2003, and June and July 2004. Species were separated at clipping into *F. hallii*, *S. curtiseta* and "other plants". The category of "other plants" included all species except *F. hallii* and *S. curtiseta*, and the contribution of each species varied among landforms (Table 3-3). The standing crop samples from the 4 sections were pooled to give an estimate for 1m^2 in each replicate plot. Locations where quadrats were clipped were not sampled again.

Table 3-2. Percentage of green standing crop removed by mowing in the May, June, July and August defoliation treatments on the 5 different landforms in central Saskatchewan.

Landform	-----May ----	----Jun. ----	-----Jul.----	----Aug. ----
North aspect-concave slope	76	81	81	82
North aspect-convex slope	74	84	77	76
South aspect-concave slope	80	76	80	80
South aspect-convex slope	74	67	72	74
Level upland	75	80	79	81

Standing crop samples were dried at 80ºC for 48 hours, sorted into green standing crop, dead standing crop and weighed. ANPP of *F. hallii*, *S. curtiseta* and other plants was determined using the incremental summation of green standing crop technique (Redmann 1991). Specifically, ANPP was determined each year by summing green standing crop in June plus positive increments in green standing crop from June to July and from July to August.

Table 3-3. Cover of bare soil, litter, and canopy cover plant species on 5 landforms in central Saskatchewan.

	------Aspect and landform------				
Cover/Species category	North aspect-concave slope	North aspect-convex slope	South aspect-concave slope	South aspect-convex slope	Level upland
	------%------				
Bare soil	0	<1	<1	<1	<1
Litter	98	98	98	97	97
Graminoids					
Agropyron dasystachyum	5	7	2	3	9
Agropyron smithii	1	2	4	1	4
Agropyron subsecundum	<1	<1	<1	<1	<1
Agropyron trachycaulum	<1	<1	<1	<1	<1
Bouteloua gracilis	0	0	1	2	0
Calamagrostis montanensis	<1	<1	0	<1	<1
Carex filifolia	0	<1	<1	<3	0
Carex pensylvanica	3	2	5	4	2
Carex sp.	3	3	3	6	2
Festuca hallii	20	22	10	2	5
Heirochloe odorata	<1	<1	0	0	0
Helictotrichon hookerii	<1	<1	<1	<1	<1
Juncus balticus	<1	0	<1	0	0
Koeleria cristata	<1	<1	<1	<1	<1
Muhlenbergia cuspidate	0	0	<1	<1	0
Muhlenbergia richardsonis	<1	<1	0	<1	0
Poa compressa	<1	<1	<1	0	0
Poa sp.	<1	<1	<1	<1	<1
Schizachyrium scoparium	<1	<1	0	0	0
Stipa comata	0	0	<1	1	0
Stipa curtiseta	9	5	11	13	11
Stipa viridula	0	0	<1	<1	<1
Forbs and Shrubs					
Achillea millefolium	<1	<1	<1	0	<1
Agoseris glauca	<1	<1	0	<1	<1
Anemone Canadensis	<1	<1	<1	<1	<1
Anemone patens	2	2	1	1	<1
Antennaria neglecta	0	<1	0	0	0
Arabis divaricarpa	0	<1	<1	<1	<1
Artemisia frigida	2	3	1	1	1
Artemisia ludoviciana	1	0	2	<1	<1
Aster ericoides	<1	<1	<1	<1	0
Aster falcatus	<1	<1	<1	<1	<1
Aster laevis	<1	<1	0	0	0
Astragalus flexulosus	<1	<1	<1	0	<1
Astragalus sp.	<1	<1	<1	<1	<1
Campanula rotundifolia	<1	<1	<1	<1	<1
Cerastium arvense	<1	<1	<1	<1	<1
Chenopodium album	<1	0	0	0	0
Cirsium floodmanii	0	<1	<1	0	0
Descurania sophia	0	0	<1	0	0
Erigeron caespitosus	<1	<1	<1	<1	<1
Erigeron glabellus	<1	0	<1	0	0
Erysimum inconspicuum	<1	<1	0	0	<1
Fragaria virginiana	0	<1	0	0	0
Gaillardia aristata	0	<1	0	0	0
Galium boreale	<1	<1	<1	<1	0
Geum triflorum	<1	<1	0	0	0
Grindelia squarrosa	0	0	0	<1	0
Haplopappus spinulosus	0	<1	0	0	0
Heuchera richardsonii	<1	<1	<1	0	0
Liatris punctata	0	0	<1	<1	0
Linum lewisii	0	0	<1	<1	0

Table 3-3 continued on next page

Table 3-3 continued from previous page

	---------------------------------------Aspect and landscape element-------------------------------				
Cover/Species category	North aspect-concave slope	North aspect-convex slope	South aspect-concave slope	South aspect-convex slope	Level upland
Lygodesmia juncea	<1	<1	<1	<1	0
Oxytropis sericea	0	<1	0	<1	0
Penstemon procerus	0	0	<1	0	0
Petalostemon purpureum	0	0	<1	<1	0
Phlox hoodii	0	<1	<1	<1	<1
Potentilla pensylvanica	<1	<1	0	0	0
Psoralea esculenta	0	<1	<1	<1	0
Rosa arkansana	1	<1	3	3	<1
Selaginella densa	<1	<1	2	4	<1
Senecio spp.	0	<1	0	<1	0
Solidaga spp.	<1	0	0	0	0
Solidago missouriensis	<1	<1	<1	<1	0
Solidago rigida	<1	<1	0	0	0
Sonchus arvensis	0	0	<1	0	<1
Sonchus sp.	<1	0	0	0	0
Stellaria longifolia	<1	0	0	0	0
Symphoricarpos occidentalis	<1	0	0	<1	0
Taraxacum officinale	<1	<1	<1	0	0
Thermopsis rhombifolia	<1	<1	<1	<1	0
Tragopogon dubius	<1	<1	<1	<1	<1
Unknown forb	<1	0	0	0	0
Vicia americana	<1	<1	<1	<1	<1
Viola sp.	0	<1	<1	<1	0
Zizia aptera	<1	<1	0	0	0

Soil water content was determined at the same time that standing crop was determined. Soil cores, 2 cm in diameter, were removed from the 0-15 cm depth at 3 random locations in each replicate plot, weighed, dried at 80ºC for 48 hours and re-weighed. Soil water content was calculated on a dry weight basis (Gardner 1982).

The plant communities within the control plots on the 5 landforms were characterized by estimating canopy cover of each species in 2001 and 2002. Twenty, 20 by 50 cm quadrats were placed at 1 m intervals in the control plots and canopy cover of plant species, bare ground and litter was recorded (Daubenmire 1959). Canopy cover was converted to percentage values and averaged over the 8 replicates. Species richness and the Shannon-Weiner diversity index were calculated for each landform using PC-ORD (McCune and Mefford 1999). Common grasses included *Agropyron dasystachyum, Agropyron smithii* (Rybd.)*, Festuca hallii, Stipa curtiseta, Stipa comata,* *Stipa viridula* (Trin.) and several *Carex* spp.. The canopy cover that each species contributed to total cover varied with topographic position (Table 3-3). *Festuca hallii* dominated north aspects, *S. curtiseta* dominated south aspects and level uplands were dominated by *S. curtiseta* and *A. dasystachyum*. The frequency of *F. hallii* ranged from 16% to 99% and was least on south aspect-convex landforms, intermediate on level uplands and south aspect-concave landforms and greatest on north aspects (Table 3-4). The frequency of *S. curtiseta* ranged from 42% to 86% and was least on north aspects and greatest on south aspects and level uplands (Table 3-4). Total canopy cover ranged from 40 to 56% and species richness ranged from 32 to 58 species per 16 m^2 (Table 3-4). Canopy cover and species richness were greatest on north aspects, intermediate on south aspects and least on level upland landforms (Table 3-4). The Shannon-Weiner diversity index ranged from 2.13 to 2.78 and was greatest on south aspects, intermediate on north aspects and lowest on the level upland landforms (Table 3-4).

Table 3-4. Total canopy cover of plants (excluding litter), species richness, the Shannon-Weiner diversity index for plant communities, and frequency of *Festuca hallii* and *Stipa curtiseta* in the control plots on the 5 landforms in central Saskatchewan.

Landform	Total canopy cover (%)	Richness (species in 16 m^2)	Shannon-Weiner diversity index (H')	-----Frequency of occurrence (%)---	
				-*Festuca hallii*-	-*Stipa curtiseta*-
North aspect-concave slope	56	54	2.52	89	61
North aspect-convex slope	56	58	2.47	99	42
South aspect-concave slope	51	52	2.60	61	76
South aspect-convex slope	52	49	2.78	16	83
Level upland	40	32	2.13	39	86

Green standing crop, dead standing crop, ANPP and soil water content in unmowed controls on the 5 landforms were compared within months of determination with analysis of variance in a randomized complete block design (Petersen 1985). Fischers' Protected Least Significant Difference (LSD) (Petersen 1985) was used to compare green standing crop, dead standing crop, ANPP and soil water content in control plots among the 5 landforms. Within years after mowing, months in which standing crop was determined, and landform element, data of green standing crop, dead standing crop and soil water content were analyzed with a randomized complete block design analysis of variance with months of mowing as the treatment (Petersen 1985). Means of green standing crop, dead standing crop, ANPP and soil water content for each month of mowing were compared to the control with Fischers' Protected LSD (Petersen 1985) within landforms. In all cases statistical significance was assumed at $P \leq 0.05$. Plants were considered recovered from mowing on the first month of at least 2 consecutive growing season months in which green standing crop and dead standing crop were not different from the unmowed control. Generally, plants were growing from May through September, therefore, the months from May through September were considered the growing season months on the study site. The number of growing season months for green standing crop and dead standing crop to recover from mowing was calculated.

4.0 RESULTS

4.1 *Festuca hallii*

4.1.1 Green Standing Crop

When compared among landforms, green standing crop of *F. hallii* was greatest on north aspects in the unmowed control, ranging from 60 to 115 g m^{-2} over the 3 years (Table 4-1). Green standing crop was intermediate on the south aspect-concave slope and level uplands and ranged from 9 to 70 g m^{-2}. The 2 to 11 g m^{-2} of green standing crop in the control on the south aspect-convex slope was least among the 5 landforms.

May mowing on the north aspect-concave slope had no affect on green standing crop of *F. hallii* (Table 4-1). Green standing crop after mowing in November was similar to that in the control the next June. Mowing in July, September or April reduced green standing crop by 22 to 64% until July of year 2 while mowing in June, August or September reduced green standing crop until June of year 3.

Green standing crop of *F. hallii* was similar to the control in the following August when the north aspect-convex slope was mowed in May (Table 4-1). Mowing in June, July, September or April reduced green standing crop by 27 to 73% until July of year 2. October or November mowing reduced green standing crop until the following June, whereas green standing crop after mowing in August matched that in the control in June of year 3. Mowing the south aspect-concave slope in May, June, July, August, October or April reduced green standing crop of *F. hallii* by 36 to 65% until June of the third year (Table 4-1). Mowing in September or November reduced green standing crop until the following August and July, respectively.

Table 4-1. Green standing crop (g m^{-2}) of *Festuca hallii* in the control and plots mowed on 5 landforms the first 3 years after mowing.

Month and order of mowing		Measurement month and year							
		Year 1			Year 2			Year 3	
		Jun.	Jul.	Aug.	Jun.	Jul.	Aug.	Jun.	Jul.
		North aspect-concave slope							
Control		63A[2]	66a[1]A	70aA	74aAB	78A	88aA	91A	115A
May		56	55a	45b	66a	89	63a	84	94
Jun.			23b	31b	53b	69	52b	89	96
Jul.				25b	49b	66	67a	87	118
Aug.					49b	67	47b	77	103
Sep.					50b	61	58b	66	96
Oct.					58b	83	71a	80	113
Nov.					61a	77	83a	86	96
Apr.					43b	73	78a	80	106
	SE	5.7	5.9	3.4	5.2	7.3	9.0	7.6	9.6
	P	0.37	<0.01	<0.01	<0.01	0.18	0.03	0.41	0.47
		North aspect-convex slope							
Control		63A	78aA	60aA	79aA	88A	66aAB	79A	114A
May		50	45b	46a	59a	74	66a	69	118
Jun.			21b	36b	53b	64	56a	71	87
Jul.				18b	43b	66	54a	78	90
Aug.					41b	57	48b	65	87
Sep.					58b	58	54a	65	96
Oct.					68a	68	73a	74	109
Nov.					61a	78	80a	87	106
Apr.					43b	72	62a	64	105
	SE	5.6	6.7	5.8	7.2	7.3	6.3	6.7	10.0
	P	0.15	<0.01	<0.01	<0.01	0.08	0.01	0.25	0.23
		South aspect-concave slope							
Control		30B	39Ba	35aB	42aB	54aAB	36aBC	42B	60B
May		16	13b	19b	21b	29b	22b	36	41
Jun.			9b	8b	11b	19b	13b	32	41
Jul.				12b	20b	28b	21b	48	53
Aug.					17b	20b	16b	30	46
Sep.					23b	31b	25a	38	53
Oct.					18b	24b	22b	37	37
Nov.					21b	39a	27a	45	47
Apr.					21b	27b	23b	36	46
	SE	4.4	5.9	4.3	4.6	6.8	4.1	6.2	7.6
	P	0.06	<0.01	<0.01	<0.01	0.02	0.02	0.51	0.5
		South aspect-convex slope							
Control		7C	8C	3C	2C	7aC	4aC	6C	11C
May		1	1	5	6	4a	1a	4	6
Jun.			1	1	3	2a	1a	5	0
Jul.				4	7	12a	15b	20	20
Aug.					5	8a	7a	15	9
Sep.					3	5a	7a	15	12
Oct.					7	5a	6a	11	10
Nov.					4	2a	5a	6	9
Apr.					10	18b	17b	17	19
	SE	4.3	2.6	1.8	2.7	3.1	3.3	5.3	5.4
	P	0.36	0.11	0.52	0.54	<0.01	0.01	0.25	0.27

Table 4-1 continued on next page

Table 4-1 continued from previous page

		Level upland							
Control		15BC	20BC	70aBC	18BC	40BC	9BC	20BC	39BC
May		21	24	45b	44	33	10	32	51
Jun.			10	31b	27	19	6	30	36
Jul.				25b	28	26	4	21	38
Aug.					24	25	10	28	46
Sep.					23	35	5	45	50
Oct.					38	47	9	43	63
Nov.					29	25	7	38	44
Apr.					28	32	7	56b	58
	SE[3]	3.4	4.9	3.4	7.1	8.1	3.4	9.4	10.1
	P[4]	0.27	0.14	<0.01	0.24	0.35	0.90	0.15	0.60
	SE[5]	6.8	9.1	8.2	11.5	12.9	11.2	10.0	14.1
	P[6]	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

[1] Means that are followed by the same letter within years, months and landforms are not different from the control.
[2] Means of the control followed by the same letter (uppercase) within years, months and landforms are not significantly ($P \leq 0.05$) different among landforms.
[3] Standard error for the comparison of the treatments within landforms.
[4] P for the comparison of the treatments within landforms.
[5] Standard error for the comparison among landforms.
[6] P for the comparison among landforms.

Green standing crop of *F. hallii* after mowing on the south aspect-convex slope in May, June or July was similar to the control the next month (Table 4-1). After mowing in August, September, October, November or April green standing crop was less than that in the control until the following June.

Mowing the level upland in May had no affect on green standing crop (Table 4-1). Green standing crop was similar to that in the control in June of year 2 after mowing in months other than May.

When all landforms are considered, 1 to 11 growing season months elapsed between the month of mowing and the first of at least 2 consecutive months in which green standing crop of *F. hallii* was similar to the control (Table 4-2). Generally, green standing crop equalled the control in fewer months after mowing on the north aspect-convex slope, south aspect-convex slope and the level upland; green standing crop took longest to become similar to the control on concave slopes. Green standing crop was reduced longer when mowed in May through October than if mowed in November or April.

Table 4-2. The number of growing season months (May through September) elapsed between the month of mowing and the first month of at least 2 consecutive months in which green standing crop and dead standing crop of *Festuca hallii* was not different (P<0.05) from the unmowed control on 5 landforms.

Month of mowing	North aspect-Concave slope	North aspect-Convex slope	South aspect-Concave slope	South aspect-Convex slope	Level upland
			Green standing crop		
Apr.	3[1,2,3]	3	7	1	2
May	1	3	11	1	1
Jun.	10	6	10	1	5
Jul.	5	5	9	1	4
Aug.	8	8	8	3	3
Sep.	7	3	4	2	2
Oct.	3	2	7	2	2
Nov.	2	2	3	2	2
			Dead standing crop		
Apr.	>8[1,2,3]	4	7	2	2
May	6	6	11	1	3
Jun.	5	7	>11	1	2
Jul.	>10	6	9	1	1
Aug.	>9	5	>9	3	3
Sep.	>8	4	7	2	2
Oct.	7	4	>8	2	2
Nov.	7	4	7	2	2

[1] The light grey pattern indicates standing crop of green phytomass after mowing was not different ($P \leq 0.05$) to the unmowed control in the same year or growing season in which mowing occurred.
[2] The clear or white pattern indicates standing crop of green phytomass after mowing was not different ($P \leq 0.05$) to the unmowed control in the first year or growing season after mowing.
[3] The dark grey pattern indicates standing crop of green phytomass after mowing was not different ($P \leq 0.05$) to the unmowed control in the second full year or growing season growing season after mowing.

4.1.2 Dead Standing Crop

Over the 3 years dead standing crop of *F. hallii* was greatest in the unmowed control on north aspects, ranging from 32 to 121 g m^{-2} (Table 4-3). Dead standing crop was intermediate on the south aspect-concave slope and level upland, and ranged from 11 to 59 g m^{-2}. Dead standing crop was least on the south aspect-convex slope and ranged from 3 to 17 g m^{-2}.

May or June mowing on the north aspect-concave slope reduced dead standing crop of *F. hallii* until June of year 2 (Table 4-3). Mowing in months other than May or June reduced dead standing crop by 27 to 72% until year 3. Mowing the north aspect-

Table 4-3. Dead standing crop (g m^{-2}) of *Festuca hallii* in the control and plots mowed on 5 landforms the first 3 years after mowing.

Month and order of mowing		Measurement month and year							
		Year 1			Year 2			Year 3	
		Jun.	Jul.	Aug.	Jun.	Jul.	Aug.	Jun.	Jul.
North aspect-concave slope									
Control		69a[1] AB[2]	63aA	32aB	71aA	53B	109aA	121aA	91A
May		19b	18b	21b	73a	75	56b	123a	102
Jun.			14b	19b	55a	38	50b	87a	83
Jul.				16b	37b	50	47b	88b	90
Aug.					33b	33	30b	81b	85
Sep.					28b	26	33b	78b	76
Oct.					39b	31	37b	97a	96
Nov.					40b	38	57b	101a	103
Apr.					25b	24	40b	71b	90
	SE	3.6	6.5	3.0	6.9	5.9	12.3	11.6	10
	P	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	0.62
North aspect-convex slope									
Control		77aA	73aA	62aA	67aAB	81aA	64AB	105A	121aA
May		17b	25b	21b	62a	62a	62	110	110a
Jun.			23b	21b	43b	48b	47	80	104a
Jul.				19b	46b	43b	42	84	91b
Aug.					31b	29b	35	72	76b
Sep.					25b	25b	32	82	88b
Oct.					23b	29b	44	81	108a
Nov.					33b	38b	44	97	122a
Apr.					32b	36b	40	86	99a
	SE	7.1	7.5	6.9	6.9	5.6	8.0	9.2	8.3
	P	<0.01	<0.01	<0.01	<0.01	<0.01	0.07	0.25	<0.01
South aspect-concave slope									
Control		41B	51aA	19aBC	43aB	41aBC	27aBC	59aB	40B
May		5	5b	7b	16b	21b	22a	41a	38
Jun.			8b	6b	14b	15b	10b	30b	39
Jul.				11b	13b	15b	17b	42a	40
Aug.					10b	11b	12b	24b	38
Sep.					18b	12b	13b	38a	48
Oct.					11b	10b	10b	35b	34
Nov.					11b	14b	15b	43a	39
Apr.					13b	13b	12b	40a	41
	SE	11.4	9.1	2.6	3.9	4.4	3.1	6.4	8.1
	P	0.06	<0.01	0.01	<0.01	<0.01	<0.01	0.04	0.99
South aspect-convex slope									
Control		17BC	12B	3C	4C	6C	3aC	11C	10B
May		1	0	4	6	3	0a	6	8
Jun.			1	0	3	1	1a	4	0
Jul.				6	7	8	13b	22	15
Aug.					9	7	6a	11	6
Sep.					4	4	6a	12	10
Oct.					4	3	4a	12	8
Nov.					4	2	4a	6	6
Apr.					9	9	9a	13	18
	SE	11.2	4.7	1.8	2.7	2.1	2.3	5.6	4.4
	P	0.35	0.17	0.20	0.70	0.13	0.01	0.50	0.21

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Table 4-3 continued from previous page

		----------Level upland----------							
Control		20aBC	18aAB	11BC	16C	28BC	31BC	26BC	37B
May		4b	6b	7	32	26	25	60	45
Jun.			5b	6	22	12	21	34	31
Jul.				4	15	14	15	27	38
Aug.					12	11	25	28	35
Sep.					12	14	20	49	34
Oct.					21	17	22	54	44
Nov.					17	12	23	34	43
Apr.					16	11	19	48	42
	SE[3]	3.6	3.6	2.0	5.3	4.7	7.2	10.5	9.1
	P[4]	0.02	0.04	0.13	0.23	0.07	0.94	0.19	0.96
	SE[5]	11.3	11.9	7.6	8.4	9.8	17.2	12.7	13.5
	P[6]	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

[1] Means that are followed by the same letter within years, months and landforms are not different from the control.
[2] Means of the control followed by the same letter (uppercase) within years, months and landforms are not significantly ($P \leq 0.05$) different among landforms.
[3] Standard error for the comparison of the treatments within landforms.
[4] P for the comparison of the treatments within landforms.
[5] Standard error for the comparison among landforms.
[6] P for the comparison among landforms.

convex slope in May reduced dead standing crop of *F. hallii* until June of year 2 (Table 4-3). By comparison, mowing in other months reduced dead standing crop by 40 to 69% until August of year 2.

May mowing on the south aspect-concave slope reduced dead standing crop by 50 to 90% until August of year 2 (Table 4-3). Mowing in all other months reduced dead standing crop by 27 to 84% until June or July of the third year. Dead standing crop on the south aspect-convex slope was similar to the control on the first date of sampling after mowing in all months (Table 4-3).

On the level upland, dead standing crop of *F. hallii* was reduced until August after mowing in May, June or July (Table 4-3). When mowed in August, September, October, November or April dead standing crop was similar to that in the control in June of year 2.

Dead standing crop of *F. hallii* was similar to that in the control 1 to 7 growing season months after mowing the convex-shaped slopes and the level upland (Table 4-2). By comparison on concave-shaped slopes, 4 to more than 11 growing season months elapsed between the month of mowing and the first month in which standing dead crop was similar to that in the control.

4.1.3 Above Ground Net Primary Production

In all 3 years, ANPP of *F. hallii* was greatest in the unmowed control on north aspects (88 to 122 g m^{-2}) (Table 4-4). ANPP was intermediate in the control on the south aspect-concave slope and level upland, ranging from 31 to 64 g m^{-2}. With a range of 8 to 11 g m^{-2}, ANPP in the control was least on the south aspect-convex slope.

Mowing the north aspect-concave slope in May or November reduced ANPP of *F. hallii* until year 2 (Table 4-4). In contrast, mowing the north aspect-concave slope in other months reduced ANPP until year 3.

May, June, October or November mowing reduced ANPP of *F. hallii* on the north aspect-convex slope until year 2 (Table 4-4). After mowing in July, August, September or April, ANPP was similar to the control in year 3.

May through October or April mowing on the south aspect-concave slope reduced ANPP of *F. hallii* until year 3 (Table 4-4). By comparison, ANPP was similar to that in the control in year 2 following mowing in November.

ANPP after mowing *F. hallii* on the south aspect-convex slope in May, June or July was similar to that in the control in year 1 (Table 4-4). Mowing in August through November, or mowing in April reduced ANPP until year 2.

After mowing the level upland in May, ANPP of *F. hallii* was similar to the control in year 1. Mowing in months other than May reduced ANPP until year 2 (Table 4-4).

Table 4-4. Above ground net primary production (ANPP) of *Festuca hallii*, *Stipa curtiseta*, and other plants (g m^{-2}) in the control and plots mowed on 5 landforms the first 3 years after mowing.

Month and order of mowing		Year 1			Year 2			Year 3	
	--*F. hallii*--	-*S. curtiseta*-	--Other--	--*F. hallii*--	-*S. curtiseta*-	--Other--	--*F. hallii*--	-*S. curtiseta*-	--Other--
North aspect-concave slope									
Control	88a[1]A[2]	32a	73a	111aA	15B	59B	122A	16B	29B
May	64b	16b	64a	94a	16	61	103	11	40
Jun.	32b	7b	33b	77b	20	57	112	22	35
Jul.	25b	4b	19b	86b	17	54	130	11	38
Aug.				71b	10	58	106	13	44
Sep.				83b	12	56	103	16	40
Oct.				90b	12	51	116	14	50
Nov.				100a	12	52	100	14	36
Apr.				83b	8	71	110	8	50
SE[3]	4.7	3.8	5.9	6.4	3.6	6.6	8.8	4.2	6.7
P[4]	<0.01	<0.01	<0.01	<0.01	0.40	0.51	0.30	0.53	0.57
North aspect-convex slope									
Control	91aA	38a	66a	99aAB	11B	56B	117A	6B	28B
May	66b	36a	53a	92a	12	63	118	6	30
Jun.	39b	34a	35b	81a	12	62	91	7	41
Jul.	18b	19b	19b	73b	12	53	104	9	35
Aug.				65b	8	69	91	8	47
Sep.				74b	9	57	96	9	27
Oct.				97a	7	45	109	7	26
Nov.				103a	5	46	113	7	35
Apr.				79b	10	43	106	7	32
SE[3]	6.3	4.0	4.3	7	2.1	6.0	9.0	1.7	5.8
P[4]	<0.01	0.01	<0.01	<0.01	0.21	0.07	0.22	0.95	0.21
South aspect-concave slope									
Control	51aB	30a	70a	64aB	34AB	76aAB	63B	29AB	50A
May	26b	22a	70a	39b	50	75a	49	39	55
Jun.	9b	15b	38b	24b	41	71a	44	32	52
Jul.	11b	5b	18b	32b	33	70a	56	24	44
Aug.				25b	33	64a	46	30	48
Sep.				35b	23	66a	53	21	53
Oct.				33b	43	61b	42	31	55
Nov.				48a	39	65a	55	28	50
Apr.				35b	31	60b	48	28	53
SE[3]	4.5	4.7	3.7	6.1	5.9	5.2	7.1	4.3	6.0
P[4]	<0.01	<0.01	<0.01	0.03	0.09	0.35	0.54	0.22	0.95

Table 4-4 continued from previous page

					South aspect-convex slope					
Control		9aC	35a	65a	8C	64A	75aAB	11C	56A	55A
May		6a	20b	60a	8	48	66a	8	52	55
Jun.		1a	14b	34b	4	54	67a	5	76	49
Jul.		4a	5b	20b	17	35	63a	24	36	54
Aug.					11	46	58b	15	59	51
Sep.					8	49	50b	15	52	50
Oct.					12	60	56b	12	69	44
Nov.					7	46	66a	12	53	56
Apr.					23	46	56b	20	52	45
	SE[3]	2.7	3.3	4.8	3.9	6.8	5.1	5.3	9.1	4.2
	P[4]	0.21	<0.01	<0.01	<0.01	0.13	0.04	0.28	0.16	0.38
					Level upland					
Control		31aBC	45a	87a	58B	47aA	84A	39BC	45A	47A
May		30a	36a	67b	68	44a	69	53	47	51
Jun.		18b	20b	46b	40	47a	80	47	45	52
Jul.		7b	7b	22b	34	34a	75	39	40	65
Aug.					36	20b	71	47	33	57
Sep.					40	22b	67	67	31	56
Oct.					51	28a	64	64	33	41
Nov.					49	28a	75	48	31	53
Apr.					51	26b	79	68	25	47
	SE[3]	4.1	4.6	5.9	9.2	6.8	8.4	10.8	9.8	8.3
	P[4]	<0.01	<0.01	<0.01	0.18	0.03	0.79	0.35	0.76	0.72
	SE[5]	8.8	6.0	6.8	13.0	9.2	7.1	13.7	9.4	6.4
	P[6]	<0.01	0.42	0.17	<0.01	<0.01	0.04	<0.01	<0.01	0.01

[1] Column means that are followed by the same letter (lower case) within years, measurement months and landforms are not significantly ($P \leq 0.05$) different from the control.
[2] Row means of the control followed by the same letter (uppercase) within years, months and landforms are not significantly ($P \leq 0.05$) different among landforms.
[3] Standard error for the comparison of the treatments within the landform.
[4] P for the comparison of the treatments within the landform.
[5] Standard error for the comparison among landforms.
[6] P for the comparison among landforms.

4.2 Stipa curtiseta

4.2.2 Green standing crop

Green standing crop of *S. curtiseta* in the unmowed controls was greatest on the south aspect-convex slope (26 to 55 g m^{-2}) (Table 4-5). Green standing crop in the control was intermediate on the south aspect-concave slope and level upland and ranged from 15 to 45 g m^{-2}. Ranging from 3 to 20 g m^{-2}, green standing crop in the control was least on north aspects.

Mowing the north aspect-concave slope had no affect on green standing crop of *S. curtiseta* (Table 4-5). By comparison, mowing the north aspect-convex slope in July reduced green standing crop until the following June; however, mowing the north aspect-convex slope in other months had no affect on green standing crop.

Mowing the south aspect-concave slope and level upland in May had no affect on green standing crop of *S. curtiseta* (Table 4-5). June mowing reduced green standing crop until the next August. Green standing crop following mowing in July through November or April was similar to that in the control in June of year 2.

May mowing had no effect green standing crop of *S. curtiseta* on the south aspect-convex slope (Table 4-5). Green standing crop was similar to that in the control in June of year 2 following mowing in other months.

Table 4-5. Green standing crop (g m^{-2}) of *Stipa curtiseta* in the control and plots mowed on 5 landforms the first 3 years after mowing.

Month and order of mowing		Year 1 Jun.	Year 1 Jul.	Year 1 Aug.	Year 2 Jun.	Year 2 Jul.	Year 2 Aug.	Year 3 Jun.	Year 3 Jul.
North aspect-concave slope									
Control		10B[2]	20AB	11B	5B	13B	14C	3B	16C
May		6	9	11	8	14	10	4	11
Jun.			6	7	7	16	12	16	21
Jul.				5	5	14	8	9	7
Aug.					4	5	6	7	13
Sep.					4	9	10	11	12
Oct.					5	6	9	9	13
Nov.					3	9	4	14	9
Apr.					3	5	6	3	8
	SE	1.6	3.8	2.6	1.9	3.2	2.8	3.7	4.2
	P	0.14	0.06	0.28	0.53	0.12	0.36	0.18	0.39
North aspect-convex slope									
Control		3B	11B	12a[1]B	3B	9B	7aC	3B	5C
May		5	11	19a	5	11	7a	4	4
Jun.			7	11a	4	10	10a	4	6
Jul.				5b	5	10	7a	6	6
Aug.					4	5	5a	4	8
Sep.					3	6	7a	6	5
Oct.					2	5	3a	6	7
Nov.					2	5	2b	5	5
Apr.					3	10	5a	5	5
	SE	0.9	3.4	3.1	0.9	2.3	1.3	1.5	1.7
	P	0.39	0.72	0.04	0.12	0.27	0.01	0.72	0.88
South aspect-concave slope									
Control		24A	22aAB	22aB	16B	31AB	23b	17AB	24aBC
May		21	25a	19a	31	28	38	24	39b
Jun.			9b	16a	31	30	32	17	29a
Jul.				6b	22	17	25	13	20a
Aug.					22	23	18	15	29a
Sep.					13	18	20	12	17a
Oct.					32	33	32	15	29a
Nov.					27	22	25	16	26a
Apr.					23	29	21	12	26a
	SE	3.9	2.9	3.2	5.5	4.6	4.5	3.4	4.3
	P	0.65	<0.01	0.01	0.17	0.16	0.06	0.30	0.04
South aspect-convex slope									
Control		26A	38aA	39aA	47A	55A	43aA	32aA	55A
May		22	29a	27b	31	41	36a	39a	44
Jun.			16b	24b	31	45	46a	47b	72
Jul.				15b	22	32	23b	23a	34
Aug.					35	41	28b	25a	58
Sep.					32	28	42a	29a	51
Oct.					38	52	40a	36a	69
Nov.					30	27	31a	33a	45
Apr.					30	36	37a	25a	51
	SE	5.3	5.1	3.9	3.1	7.0	5.1	5.2	9.34
	P	0.64	0.03	<0.01	0.30	0.34	0.03	0.04	0.14

Table 4-5 continued on next page

Table 4-5 continued from previous page

		--Level upland--							
Control		16AB	31aA	23aB	15B	37AB	31aAB	17AB	45AB
May		26	29a	28a	15	43	34a	28	47
Jun.			11b	16a	26	38	28a	27	45
Jul.				10b	8	31	24a	20	40
Aug.					12	19	9b	15	32
Sep.					8	15	15b	16	31
Oct.					12	15	26a	15	33
Nov.					13	24	19a	13	31
Apr.					9	20	17b	12	23
	SE[3]	3.3	5.2	3.9	4.7	7.5	4.5	5.7	10.0
	P[4]	0.06	0.03	0.02	0.22	0.07	<0.01	0.41	0.71
	SE[5]	4.6	6.3	5.3	7.0	10.0	5.5	5.2	9.7
	P[6]	0.01	0.04	<0.01	<0.01	0.02	<0.01	<0.01	<0.01

[1] Means that are followed by the same letter within years, months and landforms are not different from the control.
[2] Means of the control followed by the same letter (uppercase) within years, months and landforms are not significantly ($P \leq 0.05$) different among landforms.
[3] Standard error for the comparison of the treatments within landforms.
[4] P for the comparison of the treatments within landforms.
[5] Standard error for the comparison among landforms.
[6] P for the comparison among landforms.

One to 5 growing season months elapsed after mowing until green standing crop of *S. curtiseta* was similar to the control (Table 4-6). Specifically, green standing crop was similar to the control within 1 or 2 growing season months of mowing in April or May. Green standing crop was similar to the control with 1 to 5 growing season months after June or July mowing. Mowing in August, reduced green standing crop for 3 months and mowing in September, October or November reduced green standing crop for 2 growing season months.

4.2.2 Dead standing crop

Among the unmowed controls, dead standing crop of *S. curtiseta* was greatest on the south aspect-convex slope, and ranged from 29 to 58 g m^{-2} over the three years of study (Table 4-7). With a range of 23 to 46 g m^{-2}, dead standing crop in the control was intermediate on the south aspect-concave slope and level upland, and it was least in the control on north aspects (9 to 28 g m^{-2}).

Dead standing crop of *S. curtiseta* was similar to that in the control in August when the north aspect-concave slope was mowed in May, June or July (Table 4-7).

Table 4-6. The number of growing season months (May through September) elapsed between the month of mowing and the first month of at least 2 consecutive months in which green standing crop and dead standing crop of *Stipa curtiseta* was not different ($P \leq 0.05$) from the unmowed control on 5 landforms.

Month of mowing	North aspect-Concave slope	North aspect-Convex slope	South aspect-Concave slope	South aspect-Convex slope	Level upland
			Green standing crop		
Apr.	2	2	2	2	2
May	1	1	1	1	1
Jun.	1	1	2	5	2
Jul.	1	4	4	4	4
Aug.	3	3	3	3	3
Sep.	2	2	2	2	2
Oct.	2	2	2	2	2
Nov.	2	2	2	2	2
			Dead standing crop		
Apr.	4	2	7	7	7
May	3	3	6	7	3
Jun.	2	2	6	10	7
Jul.	1	1	9	9	6
Aug.	5	3	8	8	8
Sep.	4	2	7	7	7
Oct.	4	4	7	7	7
Nov.	4	4	7	7	7

[1] The light grey pattern indicates standing crop of green phytomass after mowing was not different ($P \leq 0.05$) from the unmowed control in the same year or growing season in which mowing occurred.
[2] The clear or white pattern indicates standing crop of green phytomass after mowing was not different ($P \leq 0.05$) from the unmowed control in the first year or growing season after mowing.
[3] The dark grey pattern indicates standing crop of green phytomass after mowing was not different ($P \leq 0.05$) from the unmowed control in the second full year or growing season growing season after mowing.

Mowing in August through November or April reduced dead standing crop by 65 to 82% until August of year 2.

May, June or July mowing on the north aspect-convex slope reduced dead standing crop of *S. curtiseta* until August of the same year (Table 4-7). August, September or April mowing reduced dead standing crop until August of year 2. In contrast, mowing in October and November reduced dead standing crop until June of year 3.

Mowing the south aspect-concave slope in May or June reduced dead standing crop of *S. curtiseta* until August of year 1 and July of year 2, respectively (Table 4-7). Mowing on this landform in other months reduced dead standing crop by 39 to 68% until June of year 3.

Table 4-7. Dead standing crop (g m^{-2}) of *Stipa curtiseta* in the control and plots mowed on 5 landforms the first 3 years after mowing.

Month and order of mowing		Year 1 Jun.	Year 1 Jul.	Year 1 Aug.	Year 2 Jun.	Year 2 Jul.	Year 2 Aug.	Year 3 Jun.	Year 3 Jul.
		North aspect-concave slope							
Control		28AB[2]	24a[1]BC	9B	10B	17aB	16BC	7B	16B
May		5	5b	6	9	12a	12	5	11
Jun.			8b	6	11	10a	11	9	21
Jul.				5	5	9a	8	7	7
Aug.					5	4b	6	5	13
Sep.					6	6b	6	7	12
Oct.					5	3b	6	10	13
Nov.					4	5b	3	9	9
Apr.					3	3b	4	3	8
	SE	9.0	4.9	2.2	2.1	3.0	3.2	2.9	3.8
	P	0.11	0.03	0.65	0.07	0.03	0.14	0.77	0.35
		North aspect-convex slope							
Control		6B	12aC	11B	7B	9aB	7C	7B	5B
May		2	5b	12	8	10a	8	6	4
Jun.			4b	9	7	8a	10	6	6
Jul.				5	7	9a	7	9	6
Aug.					6	4a	3	3	8
Sep.					6	5a	4	6	5
Oct.					3	2b	2	6	7
Nov.					4	3b	2	5	5
Apr.					4	7a	3	6	5
	SE	1.7	1.8	2.3	1.2	1.8	1.3	2.2	1.2
	P	0.11	0.01	0.22	0.19	0.02	<0.01	0.81	0.76
		South aspect-concave slope							
Control		38aA	25aB	28aAB	25aAB	23aB	28aAB	32A	24AB
May		11b	9b	14a	23a	23a	27a	33	30
Jun.			12b	13b	11b	18a	19a	25	19
Jul.				7b	9b	14b	13b	18	16
Aug.					11b	12b	11b	17	18
Sep.					10b	8b	8b	16	15
Oct.					13b	14b	9b	23	23
Nov.					13b	8b	14b	25	20
Apr.					8b	11b	14b	16	15
	SE	5.1	3.8	5.1	3.8	3.1	3.8	4.7	4.5
	P	<0.01	0.03	0.04	0.03	<0.01	<0.01	0.07	0.24
		South aspect-convex slope							
Control		58aA	52aAB	45aA	43aA	29AB	38aA	38A	43A
May		15b	20b	19b	29b	29	28a	44	33
Jun.			19b	20b	27b	24	23b	45	36
Jul.				16b	19b	17	19b	27	20
Aug.					17b	15	21b	29	29
Sep.					18b	19	21b	36	31
Oct.					18b	21	25b	40	38
Nov.					17b	20	17b	35	28
Apr.					20b	18	18b	29	24
	SE	11.6	4.6	5.0	4.4	3.9	3.9	5.2	6.3
	P	0.03	<0.01	<0.01	<0.01	0.18	0.02	0.13	0.29

Table 4-7 continued on next page

Table 4-7 continued from previous page

		Level upland							
Control		32aAB	40aB	24aB	46aA	46aA	27aAB	26AB	31AB
May		11a	12b	20a	30a	35a	34a	26	33
Jun.			10b	11a	16b	22b	22a	34	25
Jul.				9a	13b	17b	20a	16	29
Aug.					7b	7b	6b	15	20
Sep.					10b	8b	9b	12	19
Oct.					10b	11b	10b	17	19
Nov.					8b	10b	11b	18	20
Apr.					6b	8b	9b	16	17
	SE[3]	9.0	5.3	4.5	5.7	5.8	4.1	11.8	6.2
	P[4]	0.15	<0.01	0.09	<0.01	<0.01	<0.01	0.41	0.52
	SE[5]	10.8	7.7	6.9	8.5	7.2	5.8	7.3	9.2
	P[6]	0.04	0.01	<0.01	<0.01	0.02	<0.01	0.01	0.05

[1] Means that are followed by the same letter within years, months and landforms are not different from the control.
[2] Means of the control followed by the same letter (uppercase) within years, months and landforms are not significantly ($P \leq 0.05$) different among landforms.
[3] Standard error for the comparison of the treatments within landforms.
[4] P for the comparison of the treatments within landforms.
[5] Standard error for the comparison among landforms.
[6] P for the comparison among landforms.

May mowing reduced dead standing crop on the south aspect-convex slope until July of year 2 (Table 4-7). In contrast, mowing in other months reduced dead standing crop until June of year 3.

Mowing in May reduced dead standing crop on the level upland landform until August (Table 4-7). June or July mowing reduced dead standing crop by 65 and 72%, respectively, until August of year 2. Dead standing crop was reduced until June of year 3 after mowing in August through November or April.

Dead standing crop of *S. curtiseta* was reduced for 1 to 10 growing season months following mowing (Table 4-6). Following mowing on north aspects, dead standing crop generally equalled the control 3 to 8 growing season months sooner than dead standing crop on south aspects and the level upland landform.

4.2.3 Above Ground Net Primary Production

Over the 3 years, ANPP of *S. curtiseta* was greatest in the unmowed control on the south aspect-convex slope and level upland, ranging from 35 to 64 g m^{-2} (Table 4-4). ANPP was intermediate on the south aspect convex slope (30 to 34 g m^{-2}) and least (6 to 38 g m^{-2}) on north aspects.

ANPP of *S. curtiseta* equalled the control in year 2 following mowing on the north aspect-concave slope (Table 4-4). Mowing the north aspect-convex slope in May or June had no affect on ANPP, but mowing from July through November or in April reduced ANPP until the second year.

Above ground net primary production of *S. curtiseta* following mowing of the south aspect-convex slope equalled the control in year 2 (Table 4-4). ANPP was similar to the control in year 1 after mowing the south aspect-concave slope in May. Mowing the south aspect-convex slope in other months reduced ANPP of *S. curtiseta* until year 2.

Above ground net primary production of *S. curtiseta* on the level upland landform after May mowing was always similar to the control (Table 4-4). Following mowing in June, October or November ANPP was similar to the control in year 2. Above ground net primary production after the July, August, September or April mowing was reduced until year 3.

4.3 "Other" plants

4.3.1 Green Standing Crop

In June and July of year 2 and July of year 3, green standing crop of "other" plants was greatest in the unmowed control on south aspects and the level upland ranging from 47 to 71 g m^{-2} (Table 4-8). Green standing crop was intermediate on the north aspect-concave slope (24 to 50 g m^{-2}) and least (20 to 39 g m^{-2}) on the north aspect-convex slope. Green standing crop ranged from 35 to 74 g m^{-2} in the control and was similar among landforms in year 1, August of year 2 and June of year 3.

Table 4-8. Green standing crop (g m^{-2}) of "other" plants in the control and plots mowed on 5 landforms the first 3 years after mowing.

Month and order of mowing	Year 1 Jun.	Year 1 Jul.	Year 1 Aug.	Year 2 Jun.	Year 2 Jul.	Year 2 Aug.	Year 3 Jun.	Year 3 Jul.
	North aspect-concave slope							
Control	57	42a[1]	39a	34B[2]	50BC	36	25	24BC
May	44	58b	55a	30	52	49	31	37
Jun.		25b	28a	26	54	41	21	34
Jul.			19b	33	48	36	30	36
Aug.				24	41	50	34	41
Sep.				24	47	38	36	32
Oct.				25	49	30	38	38
Nov.				26	52	36	24	35
Apr.				26	55	49	36	47
SE	6.8	4.7	5.5	4.0	6.2	6.8	4.9	7.5
P	0.24	<0.01	<0.01	0.55	0.85	0.44	0.28	0.68
	North aspect-convex slope							
Control	48	46a	42a	39B	37C	41a	26	20C
May	49	43a	33a	38	41	37a	27	25
Jun.		25b	34a	47	47	33a	36	32
Jul.			19b	30	39	45a	23	34
Aug.				37	48	49a	34	40
Sep.				37	41	41a	23	23
Oct.				26	43	28b	25	21
Nov.				28	36	28b	31	18
Apr.				26	35	34a	30	26
SE	5.3	4.5	4.1	5.0	5.24	4.3	5.4	0.03
P	0.97	<0.01	<0.01	0.05	0.65	0.04	0.69	4.7
	South aspect-concave slope							
Control	57	55a	50a	47aB	71A	52	35	47A
May	53	70a	49a	50a	67	62	40	45
Jun.		31b	34a	49a	69	53	39	51
Jul.			18b	40a	67	49	33	44
Aug.				37b	52	54	42	48
Sep.				34b	63	49	39	53
Oct.				37b	56	51	39	55
Nov.				39a	58	52	43	48
Apr.				37b	55	46	41	53
SE	3.0	5.7	5.5	3.4	5.5	4.6	4.2	6.3
P	0.36	<0.01	<0.01	<0.01	0.16	0.46	0.76	0.93
	South aspect-convex slope							
Control	61a	51a	46a	47aB	71A	57a	44	48A
May	39b	44a	57a	45a	62	50a	44	49
Jun.		25b	33a	48a	52	48a	36	48
Jul.			20b	39a	54	42b	40	53
Aug.				32b	55	41b	42	47
Sep.				31b	49	36b	39	48
Oct.				36a	43	43b	35	39
Nov.				36a	58	52a	48	54
Apr.				34b	53	41b	42	37
SE	3.7	9.4	5.1	4.5	5.7	4.2	4.0	4.0
P	<0.01	<0.01	<0.01	0.05	0.07	0.02	0.39	0.08

Table 4-8 continued on next page

Table 4-8 continued from previous page

		------Level upland------							
Control		74a	66	59a	69A	57AB	49	43	39B
May		49b	53	41a	50	46	43	43	46
Jun.			33	40b	56	72	50	36	43
Jul.				22b	54	64	57	58	38
Aug.					42	60	50	42	41
Sep.					42	57	48	45	42
Oct.					32	51	44	39	34
Nov.					47	62	44	48	41
Apr.					44	61	50	41	45
	SE[3]	5.1	11.0	6.2	7.6	7.1	6.8	8.8	7.4
	P[4]	0.01	<0.01	<0.01	0.07	0.35	0.91	0.84	0.96
	SE[5]	7.1	7.4	7.3	6.6	6.0	6.2	5.6	6.5
	P[6]	0.18	0.21	0.34	<0.01	<0.01	0.17	0.06	0.01

[1] Means that are followed by the same letter within years, months and landforms are not different from the control.
[2] Means of the control followed by the same letter (uppercase) within years, months and landforms are not significantly ($P \leq 0.05$) different among landforms.
[3] Standard error for the comparison of the treatments within landforms.
[4] P for the comparison of the treatments within landforms.
[5] Standard error for the comparison among landforms.
[6] P for the comparison among landforms.

Mowing the north aspect-concave slope in May had no influence on green standing crop of “other” plants (Table 4-8). June mowing reduced green standing crop by 40% until August. Green standing crop was similar to the control in June of year 2 after mowing in months other than May and August.

June or July mowing on the north aspect-convex slope reduced green standing crop until August of year 1 and June of year 2, respectively (Table 4-8). Mowing in other months had no affect on green standing crop.

May mowing the south aspect-concave slope had no impact on green standing crop (Table 4-8). Mowing in June reduced green standing crop by 44% until the next August. Green standing crop following a mowing in July or November was similar to the control in June of year 2. While mowing in August, September, October or April reduced green standing crop by 21 to 28% until July of year 2.

May mowing reduced green standing crop of “other” plants on the level upland landform by 34% until July of year 1 (Table 4-8). Green standing crop was similar to the control in June of year 2 after mowing in months other than May.

One to 8 growing season months passed after mowing until green standing crop of "other" plants was similar to the control (Table 4-9). Aside from the south aspect-convex slope, green standing crop was similar to the control within 1 to 4 growing season months after mowing. With the exception of the south aspect convex slope, green standing crop after mowing was similar to that in the control 1 to 2 months sooner when mowed in April, May or June than if mowed later. Green standing crop equalled the control within 2 to 8 growing season months after mowing on the south aspect-convex slope. Green standing crop was reduced for 2 to 8 growing season months when mowed in August or September.

Table 4-9. The number of growing season months (May through September) elapsed between the month of mowing and the first month of at least 2 consecutive months in which green standing crop and dead standing crop of "other " plants was not different ($P \leq 0.05$) from the unmowed control on 5 landforms.

Month of mowing	North aspect-Concave slope	North aspect-Convex slope	South aspect-Concave slope	South aspect-Convex slope	Level upland
			Current year standing crop		
Apr.	2	2	3	7	2
May	3	1	1	2	2
Jun.	2	2	2	2	2
Jul.	4	4	4	4	4
Aug.	3	3	3	8	3
Sep.	2	2	3	7	2
Oct.	2	2	3	2	2
Nov.	2	2	2	2	2
			Dead standing crop		
Apr.	3	3	7	7	7
May	2	1	11	3	7
Jun.	2	5	10	2	6
Jul.	4	5	9	1	5
Aug.	5	3	8	5	7
Sep.	7	3	7	7	3
Oct.	7	3	7	7	7
Nov.	4	3	7	4	7

[1] The light grey pattern indicates standing crop of green phytomass after mowing was not different ($P \leq 0.05$) from the unmowed control in the same year or growing season in which mowing occurred.
[2] The clear or white pattern indicates standing crop of green phytomass after mowing was not different ($P \leq 0.05$) from the unmowed control in the first year or growing season after mowing.
[3] The dark grey pattern indicates standing crop of green phytomass after mowing was not different ($P \leq 0.05$) to the unmowed control in the second full year or growing season growing season after mowing.

4.3.2 Dead Standing Crop

Dead standing crop of "other" plants was greatest in the unmowed control on level uplands, and ranged from 45 to 107 g m^{-2} (Table 4-10). Dead standing crop was generally least on other landforms, ranging from 12 to 71 g m^{-2}.

Dead standing crop of "other" plants was similar to the control in July of year 1 after mowing the north aspect-concave slope in May (Table 4-10). Mowing in June or July reduced dead standing crop until August. August or November mowing reduced dead standing crop by 64 and 45%, respectively, until August of year 2. September or October mowing reduced dead standing crop by 46 to 58% until June of year 3 while mowing in April had no affect on dead standing crop.

May mowing on the north aspect-convex slope had no affect on dead standing crop (Table 4-10). Dead standing crop was less than the control until June of year 2 after mowing in June or August. Mowing in July, September, October, November or April reduced dead standing crop by 54 to 60% until July of year 2.

Dead standing crop on the south aspect-concave slope was reduced by 30 to 69% until June of year 3 (Table 4-10). May mowing on the south aspect-convex slope reduced dead standing crop until the following August (Table 4-10). Dead standing crop was similar to the control in August of year 2 following mowing in June, July, August or November. September, October or April mowing reduced dead standing crop by 36 to 65% until June of year 3.

Dead standing crop was similar to the control in July of year 2 after mowing the level upland landform in June, July, August or September (Table 4-10). Mowing in

Table 4-10. Dead standing crop (g m^{-2}) of "other" plants in the control and plots mowed in 5 landforms the first 3 years after mowing.

Month and order of mowing		Measurement month and year							
		Year 1			Year 2			Year 3	
		Jun.	Jul.	Aug.	Jun.	Jul.	Aug.	Jun.	Jul.
		North aspect-concave slope							
Control		53a[1]B[2]	22aB	21B	26C	22aB	26aBC	18B	17
May		8b	14a	15	22	22a	28a	17	22
Jun.			12b	13	17	19a	27a	13	18
Jul.				13	17	16a	15a	19	21
Aug.					15	8b	15a	12	15
Sep.					11	10b	14b	24	27
Oct.					13	9b	11b	23	16
Nov.					17	12b	16a	12	22
Apr.					15	14a	12b	13	15
	SE	9.2	2.7	2.5	3.5	3.1	4.1	4.4	2.9
	P	0.01	0.04	0.09	0.13	<0.01	0.03	0.47	0.08
		North aspect-convex slope							
Control		50B	28aB	23aB	28aC	18B	23C	12B	11
May		10	13a	16b	16b	19	15	14	12
Jun.			8b	13b	21a	13	13	25	15
Jul.				13b	17b	14	21	14	18
Aug.					21a	13	15	19	24
Sep.					13b	14	18	12	11
Oct.					11b	12	9	12	9
Nov.					12b	10	8	10	11
Apr.					13b	11	10	17	11
	SE	5.3	3.9	2.3	3.3	2.9	3.3	3.8	3.6
	P	0.97	<0.01	0.02	0.01	0.32	0.06	0.15	0.13
		South aspect-concave slope							
Control		71B	40aB	20B	58aB	54aA	46aAB	43A	33
May		18	20b	21	41b	31b	31b	28	41
Jun.			21b	16	38b	31b	26b	34	26
Jul.				17	29b	30b	22b	28	23
Aug.					29b	25b	24b	30	35
Sep.					18b	18b	20b	31	28
Oct.					21b	19b	22b	25	36
Nov.					21b	20b	20b	36	38
Apr.					24b	19b	20b	31	27
	SE	3.0	4.4	3.8	5.8	4.2	3.5	4.9	5.3
	P	0.36	<0.01	0.82	<0.01	<0.01	<0.01	0.35	0.24
		South aspect-convex slope							
Control		64aB	46aB	29B	36aB	46aA	36aBC	30AB	23
May		20b	20b	28	41a	37a	44a	31	33
Jun.			21b	25	27a	26b	24a	25	29
Jul.				20	24a	23b	24a	29	19
Aug.					20b	21b	25a	18	20
Sep.					21b	16b	16b	21	21
Oct.					25a	17b	19b	28	29
Nov.					23b	23b	33a	29	28
Apr.					23b	21b	19b	26	23
	SE	3.7	5.7	4.1	4.3	4.7	5.0	3.6	4.0
	P	<0.01	<0.01	0.37	0.02	<0.01	<0.01	0.22	0.16

Table 4-10 continued on next page

Table 4-10 continued from previous page

		Level upland							
Control		107aA	78aA	45aA	101aA	51A	61aA	45A	32
May		18b	19b	22b	57b	38	50a	37	37
Jun.			27b	21b	58b	47	62a	30	39
Jul.				19b	45b	41	52a	46	33
Aug.					31b	40	36b	28	21
Sep.					34b	31	38a	32	34
Oct.					21b	27	33b	27	36
Nov.					27b	36	27b	36	39
Apr.					34b	32	36b	37	32
	SE[3]	5.1	8.8	3.3	6.7	6.7	8.6	7.8	6.4
	P[4]	0.01	<0.01	<0.01	<0.01	0.28	0.04	0.60	0.43
	SE[5]	11.7	10.1	5.1	10.1	6.7	7.1	6.9	6.4
	P[6]	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.10

[1] Means that are followed by the same letter within years, months and landforms are not different from the control.
[2] Means of the control followed by the same letter (uppercase) within years, months and landforms are not significantly ($P \leq 0.05$) different among landforms.
[3] Standard error for the comparison of the treatments within landforms.
[4] P for the comparison of the treatments within landforms.
[5] Standard error for the comparison among landforms.
[6] P for the comparison among landforms.

October, November or April reduced dead standing crop by 29 to 80% until June of year 3.

Dead standing crop of “other” plants was similar to the control within 1 to 11 growing season months of mowing (Table 4-9). Following mowing, dead standing crop was reduced for 7 to 11 growing season months on the south aspect-concave slope and 1 to 7 months on other landforms.

4.3.3 Above Ground Net Primary Production

In year 1, ANPP of “other” plants in the control was similar among landforms, and ranged from 65 to 87 g m^{-2}. With a range of 47 to 84 g m^{-2}, ANPP was greatest on south aspects and the level upland in year 2 and year 3. ANPP was least on north aspects, ranging from 28 to 59 g m^{-2}. ANPP of “other” plants on north aspects was similar to the control in year 1 following May mowing (Table 4-4). Mowing in months other than May reduced ANPP until year 2.

Following mowing in May, ANPP of “other” plants on the south aspect-concave slope was similar to that in the control in year 1 (Table 4-4). Mowing in June through

September reduced ANPP until year 2. ANPP was reduced until year 3 after mowing in October or April.

ANPP of "other" plants on the south aspect-convex slope after May mowing was similar to the control in year 1 (Table 4-4). By comparison, mowing in June, July or November reduced ANPP until year 2. August, September, October or April mowing reduced ANPP until year 3. ANPP of "other" plants was reduced until year 2 on the level upland landform (Table 4-4).

4.4 Soil Water Content

Soil water content was similar in the unmowed controls among landforms in June and July of year 1, August of year 2 and June and July of year 3 (Table 4-11). In August of year 1, soil water content was greatest on north aspects and the level upland and least on the south aspect-convex slope. Soil water content on the south aspect-concave slope did not differ from other landforms in August of year 1.

Soil water content was greatest on the north aspect-concave slope and least on the south aspect-convex slope in June and July of year 2 (Table 4-11). The north aspect-convex slope had more soil water content than the south aspect-convex slope in July of year 2. Soil water content on the north aspect-convex slope was similar among other landforms; however, the amount of soil water content was intermediate on the south aspect-concave slope and level upland.

Mowing reduced, increased or had no affect on soil water (Table 4-11). Except for mowing on the north aspect-concave slope in May, August or November, mowing reduced soil water by 15 to 23% in July of year 2. July or April mowing reduced soil water by 14 and 21%, respectively, in August of year 2.

Table 4-11. Soil water content (%) at the 0-15 cm depth in the first 3 years after mowing on 5 landforms.

Month and order of mowing		Measurement month and year							
		Year 1			Year 2			Year 3	
		Jun.	Jul.	Aug.	Jun.	Jul.	Aug.	Jun.	Jul.
North aspect-concave slope									
Control		23[1,2]	24	15A	24A	13aA	14a	19	16
May		24	23	16	21	12a	14a	20	17
Jun.			20	17	23	11b	12b	18	15
Jul.				18	24	11b	13a	18	15
Aug.					24	13a	13a	19	15
Sep.					24	11b	12a	18	15
Oct.					24	11b	13a	20	15
Nov.					23	10b	13a	19	17
Apr.					24	12a	11b	18	15
	SE	1.0	1.2	0.9	1.1	0.8	0.7	1.7	1.9
	P	0.56	0.16	0.13	0.77	0.04	0.03	0.25	0.59
North aspect-convex slope									
Control		20	23a	14aA	21aAB	12AB	14	19	15
May		20	21b	15a	20a	11	12	18	15
Jun.			22a	16b	22a	10	13	18	15
Jul.				17b	21a	13	12	18	15
Aug.					23b	11	12	18	14
Sep.					24b	10	12	18	15
Oct.					23b	11	13	17	13
Nov.					24b	12	13	18	14
Apr.					23b	13	13	18	14
	SE	1.0	0.5	0.6	0.6	0.7	0.5	1.1	1.2
	P	0.89	0.04	0.03	<0.01	0.06	0.39	0.75	0.60
South aspect-concave slope									
Control		21a	22	13AB	22AB	11aB	18	18	13
May		18b	20	12	22	11a	9	17	14
Jun.			21	13	23	10a	10	16	13
Jul.				13	22	8b	10	16	11
Aug.					23	10a	9	16	13
Sep.					24	11a	11	16	15
Oct.					20	10a	10	16	12
Nov.					20	11a	10	16	12
Apr.					22	9a	10	17	13
	SE	0.8	0.7	0.7	1.0	0.6	2.4	1.8	2.1
	P	0.04	0.29	0.74	0.63	0.03	0.27	0.52	0.07
South aspect-convex slope									
Control		17	20	11aB	20B	9C	9	15	11
May		15	16	9b	17	8	8	14	10
Jun.			18	10a	19	8	7	14	10
Jul.				11a	19	10	9	14	11
Aug.					18	9	8	14	10
Sep.					19	9	8	14	10
Oct.					16	8	8	14	11
Nov.					19	8	8	14	10
Apr.					19	8	9	13	10
	SE	1.0	1.7	0.4	1.0	0.7	0.4	0.8	0.3
	P	0.15	0.25	0.11	0.90	0.19	0.42	0.63	0.35

Table 4-11 continued on next page

Table 4-11 continued from previous page

	Level upland							
Control	22	20a	14A	21AB	11B	12	16	13
May	18	17b	12	19	11	10	16	12
Jun.		20a	13	19	10	10	15	13
Jul.			15	20	10	10	15	13
Aug.				19	10	10	16	12
Sep.				19	10	10	16	13
Oct.				21	12	11	16	13
Nov.				21	10	11	17	13
Apr.				17	10	11	16	12
SE[3]	1.4	0.8	0.7	0.9	0.6	0.5	1.1	1.2
P[4]	0.12	0.02	0.11	0.20	0.21	0.08	0.53	0.96
SE[5]	1.6	1.4	0.8	1.1	0.6	3.2		
P[6]	0.18	0.30	<0.01	0.05	<0.01	0.36		

[1] Means that are followed by the same letter within years, months and landforms are not different from the control.
[2] Means of the control followed by the same letter (uppercase) within years, months and landforms are not significantly ($P \le 0.05$) different among landforms.
[3] Standard error for the comparison of the treatments within landforms.
[4] P for the comparison of the treatments within landforms.
[5] Standard error for the comparison among landforms.
[6] P for the comparison among landforms.

Mowing the north aspect-convex slope in May reduced soil water content by 9% in July of year 1 (Table 4-11). Soil water content was greater than the control in August of year 1 after mowing in June or July. Soil water content was 10 to 14% greater in June of year 2 when mowed in the previous August through November or in April.

Mowing the south aspect-concave slope in May reduced soil water content by 14% in June of year 1 (Table 4-11). July mowing reduced soil water content by 27% in July of year 2.

Mowing the south aspect-convex slope in May reduced soil water content by 18% in August of year 1. Mowing the level upland in May reduced soil water content by 15% in July of year 1.

5.0 DISCUSSION

This study was designed to provide information that can be used to develop grazing systems in the Northern Mixed Prairie. The purpose of this study was to: 1) determine the amount of time elapsed after mowing to a 7.5 cm height in 8 different months until green standing crop, dead standing crop and ANPP of *F. hallii*, *S. curtiseta* and "other" plants was similar to an unmowed control within 5 landforms; 2) compare green standing crop, dead standing crop, and ANPP of *F. hallii*, *S. curtiseta* and "other" plants, and soil water among unmowed control plots on 5 landforms, and; 3) determine the effects of mowing in 8 different months on soil water content on 5 landforms.

Depending on the month of mowing, green standing crop, dead standing crop and ANPP of *F. hallii*, *S. curtiseta* and other plants were reduced for varying lengths of time. Plant morphology, competition, the stage of plant growth and environmental conditions before and after mowing are recognized as important factors influencing plant growth after mowing.

Soil water content is often cited as the dominant factor controlling plant growth after defoliation (Johnston et al. 1971, Dormaar et al. 1989, Redmann et al. 1993, Willms et al. 2002). In the present study soil water content was usually not influenced by landform or by mowing. Occasionally soil water content was reduced or increased after mowing. Reduced soil water content after mowing is attributed to changes in the microenvironment from mowing (Whitman 1974). Mowing removes plant material and exposes the soil to wind and solar radiation, which in turn increases evaporation. Increased soil water content after mowing is attributed to the removal of plant material, thus reducing transpiration and water uptake in plants (Patton and Nyren 1998).

Unmowed plants had more leaf area than mowed ones and consequently more soil water may have been lost through transpiration (Painter and Detling 1981, Patton and Nyren 1998). Generally soil water content was not affected by mowing. Therefore, the hypothesis that soil water content is similar among months of mowing is accepted.

Differences in slope aspects create differences in soil water content among landforms (Ayadd and Dix 1968, Leifers and Larkin-Leifers 1987). As solar radiation increases, temperatures become warmer and a decrease in soil water content is expected. Warmer soil temperatures and greater solar radiation on south aspects and uplands than on north aspects were observed on the study site in 2003 and 2004 (Braun 2005). Despite predicted differences in soil water content on different landforms, soil water content was generally similar among landforms. It is suggested that enough litter was present on all landforms to moderate soil water content among landforms on the study site. Litter insulates the soil and shades the soil from direct solar radiation on undisturbed Mixed Grass Prairie (Willms et al. 1993). Soil water content may vary among landforms because of overland flow after rainfall events. More than 25 mm of rain per day is required to generate overland flow; therefore overland flow rarely contributes to topographic redistribution of water on hummocky landscapes in Saskatchewan (Hayashi et al. 1998). Few, if any, rainfall events >25 mm occurred during the sampling period and differences in soil water content among landforms were not observed. The hypothesis that soil water content is similar among landforms is accepted.

A difference in species composition among landforms suggests that growing conditions differ among landforms (Redmann 1975). Most studies suggest precipitation and soil water content control the distribution and abundance of species in natural plant communities (Wight and Black 1978, Newbauer et al. 1980, Looman 1980, Anderson and Holte 1981, Barnes et al. 1983, Schulze et al. 1987, Maschinski and Whitman 1989, Loeser et al. 2004). The Northern Mixed Prairie occurs in a semi-arid environment where plant production is often a function of precipitation and available soil water (Smoliak 1986, Sala et al. 1988). The amount of water available to plants determines the intensity and duration of production in the Mixed Prairie (Redmann 1975, Pearcy et al. 1987, Braun 2005). Similar soil water and different plant communities among landforms are evidence that production and species composition are not solely dependent on soil water. Increased soil water content leads to increased production, suggesting plants on the study site adjust production according to the available soil water and soil water content is moderated through production (Pearcy et al. 1987). The importance of soil water content is not downplayed, but the growing conditions influenced by slope aspect and slope shape may be as important as soil water content on plant production and composition in the Northern Mixed Prairie.

Photosynthesis provides the energy for plant growth and maintenance. Other studies emphasized the importance of photosynthesis for growth of grasses after defoliation in the Northern Mixed Prairie (Harrison and Romo 1994, Kowalenko and Romo 1998). Similarly, it is concluded in the present study that mowing had less affect on plant growth when plants could photosynthesize after mowing than if conditions were not suitable for photosynthesis after mowing. Most growth of *S. curtiseta* and *F. hallii* occurs in May, June and early July (Stout et al. 1981, Willms 1988b, Redmann 1975) when precipitation and soil water content are generally greatest in the Northern

Mixed Prairie (Colberg and Romo 2002). Although both grasses grow during the same general period, *F. hallii* initiated growth earlier and grew more rapidly over a shorter period than *S. curtiseta*. Growth of *S. curtiseta* was more gradual than *F. hallii*. Plant regrowth after herbage removal depends primarily on photosynthesis after defoliation (Richards and Caldwell 1985, Briske and Richards 1995). The morphological and physiological attributes of *F. hallii* and *S. curtiseta* combined with environmental conditions before, during and after mowing may be responsible for varied lengths of time for which green standing crop, dead standing crop and ANPP were reduced. *Festuca hallii* grew more quickly after mowing, when mowed in the spring or when mowed in late fall when compared to mowing in the summer. In contrast, mowing *S. curtiseta* after June reduced green standing crop through the following May and June.

Festuca hallii and *S. curtiseta* recovered green standing crop, dead standing crop and ANPP at different rates. A difference in green standing crop, dead standing crop and ANPP after mowing the 2 grasses emphasizes the species-specific regrowth potential. Different rates of recovery may be related to the meristematic characteristics of the shoots and the location of the meristematic tissue at the time of mowing. Grasses can have long or short shoots (Dahl and Hyder 1977). Short shoots have the meristematic tissue closer to the ground, thereby avoiding removal by defoliation (Welch 1968). Meristematic tissue of long shoots can be elevated and possibly removed by defoliation.

The potential to regain ANPP, green standing crop and therefore dead standing crop is based on the time of growth, activity of intercalary, apical and axillary meristems in combination with environmental variables and resource availability (Briske and Richards 1995). *Festuca hallii* and *S. curtiseta* were growing in a mixed sward and it is assumed the environmental variables and resource availability were similar for both species. Shoots that retain meristematic tissue can regrow faster than shoots in which the meristematic tissue is damaged or removed (Dahl and Hyder 1977). Like other grasses, *F. hallii* is more tolerant to grazing at some growth stages than others (Richards and Caldwell 1985, McLean and Wikeem 1985, Busso et al. 1990). *Festuca hallii* is most tolerant of herbage removal when grazed before growth begins or in early growth when intercalary and apical meristems are located near the ground. Growth of shoots can continue after mowing because the meristematic tissue is located close to the ground and these tissues avoided being damaged from mowing. Therefore, *F. hallii* can grow after April or May mowing and in the absence of another defoliation can photosynthesize the remainder of the growing season. Meristematic tissue removed by mowing after internode elongation reduces plant growth and photosynthetic plant material for the remainder of the growing season. More time was needed for *F. hallii* to regain green standing crop when mowing disrupted photosynthesis. *Festuca hallii* is beginning to grow or it is not yet growing in April and May where the study was conducted. Mowing in April and May had small effects on the growth of plants, presumably in part, because little or no green plant material was removed.

With the exception that meristematic tissue of *S. curtiseta* remains close to the ground for longer, a similar conclusion is suggested for growth of this grass after mowing. Growth of *S. curtiseta* is more prolonged over the growing season and the grass regrew faster than *F. hallii*. Although the height of growing points was not measured in the present study, the growing points of *S. curtiseta* may have avoided damage when mowed during April through June; however, meristematic tissue was likely damaged when mowed later in the growing season. Avoiding damage from mowing in April, May or June is reflected in green standing crop being reduced for less time than when mowed after June. *Stipa curtiseta* regained ANPP and green standing crop in the same growing season when mowed in April, May or June. Internode elongation and therefore elevation of the meristematic tissue probably occurs after June in *S. curtiseta*. *Stipa curtiseta* regained ANPP, green standing crop, dead standing crop sooner when mowed once in April through June than if mowed once after June.

Peterson (1962) suggested that *S. comata* persists under heavy grazing because growth is rapid after grazing. *Stipa curtiseta* grows in May through July (Redmann 1993) and regrowth after clipping in these months was fastest. *Stipa curtiseta* is similar to *S. comata* because it can rapidly grow after mowing and therefore maintains the potential to photosynthesize and regrow above ground plant material. Unlike *S. comata* (Wright 1967), *S. curtiseta* appears to have very little potential for growth after July, regardless of whether or not the plant is defoliated.

The time needed for *S. curtiseta* and *F. hallii* to recover after mowing may be related to the characteristics of the meristematic tissue, and where growth originates for the two species. Grazing tolerant plants quickly activate meristematic tissue after defoliation (Briske and Richards 1995). *S. curtiseta* may allocate energy to growing shoots sooner after defoliation than *F. hallii*. Regrowth can also be rapid from intercalary and apical meristems if they are active and below the height of mowing. Axillary meristems produce new tillers and regrowth from these tillers is slower than growth from intercalary and apical meristems (Briske and Richards 1995). Intercalary and apical meristems of *F. hallii* may have been elongated and removed when mowed in

June or later. Therefore, new growth must have originated from new tillers. New tillers develop from axillary meristems in the crown, a time consuming process compared to regrowth from existing tillers (Dahl and Hyder 1977). Species with elevated growing points are generally more adversely affected by defoliation than species with lower growing points because meristematic tissue is removed (Stout et al. 1980, Willms and Fraser 1992). It is possible that initiating new tillers is slow for *F. hallii* and growth did not occur until the following May through July. Another reason *S. curtiseta* recovers ANPP sooner than *F. hallii* may be that *S. curtiseta* does not elevate intercalary and apical meristems until after June; therefore growth after mowing in April, May and June may have been from active meristematic tissues.

F. hallii regained green standing crop faster after mowing in October or November than after mowing in June through September. Mowing in October or November removed plant material that was no longer photosynthetically active. Removing this dead standing plant material did not interrupt the ability of plants to photosynthesize and plants regrow the following spring. Plant vigour of *F. scabrella* was greater and plant mortality was less when photosynthetic tissue remained on plants (McLean and Wikeem 1985). McLean and Wikeem (1985) also concluded that fall defoliation does not affect vigour or survival of *F. scabrella*. Willms (1991) and Willms et al. (1985) suggested that grazing in the fall and winter has less affect on *F. scabrella* var. *campestris* (Rydb.) than grazing during the growing season. In the present study, uninterrupted growth during spring and early summer allowed plants to regrow sooner after mowing in October, November, April or May than if mowed when plants were growing in June through September.

Two exceptions to the general conclusions regarding the relationships between the month of mowing and how long green standing crop of *S. curtiseta* was reduced were observed. After mowing *S. curtiseta* on the south aspect-convex slope in June, green standing crop was reduced until the next growing season. In contrast, green standing crop of *S. curtiseta* was similar to the unmowed control within 1 month of mowing in July on the north aspect-concave slope. Redmann (1991) suggested that slope and aspect influence the temperature and plant growth. South aspects are exposed to more solar radiation and are the warmest slope aspect in the Northern Mixed Prairie (Ayyad and Dix 1964, Braun 2005). The convex-shape of slopes exposes them to more wind than other landforms and, therefore, snow cover does not persist as long as concave-shaped slopes (Braun 2005). North aspects receive less solar radiation than south aspects and level uplands (Ayyad and Dix 1964, Braun 2005). Concave slopes are less exposed to wind and tend to collect snow from the surrounding landscape (Braun 2005). Less solar radiation and more snow create cooler conditions in the spring on the north aspect-concave slope (Braun 2005). *Stipa curtiseta* grew earlier in the spring on the south aspect-convex slope than on other landforms. Temperatures are cooler on the north aspect-concave slope and plants grow slower than on other landforms. Nitrous Oxide emissions began earlier in the spring on south aspects than on north aspects suggesting temperatures are warm enough for plant growth to start sooner on the south aspects (Braun 2005).

Above ground net primary production of *F. hallii* was greater on north aspects than on south aspects and the level upland. Greater ANPP on north aspects than on south aspects is attributed to cooler and moister conditions, improved soil development and more fertile soil (Ayadd and Dix 1964, Baines 1973). Above ground net primary production is an indication of plant vigour (Coupland 1974). Above ground net primary production of mowed plants was not different from ANPP in the control, suggesting that the plants had similar vigour and the ability to maintain their position in the community (Coupland 1974). With the exception of the south aspect-concave slope mowed in May or November, ANPP was similar to the control in all landforms in year 2. Above ground net primary production following mowing in April or October was reduced longer than when mowed in May or November. Regaining ANPP sooner after mowing in November than after mowing in other months suggests that plants are less susceptible to mowing in November than other months. Green standing crop was reduced the same amount of time when mowed in October or November. It is not apparent why ANPP after mowing in April did not elicit a similar response to mowing in November or May. The hypotheses that ANPP of *F. hallii* is similar among landforms and among months of mowing are rejected.

Above ground net primary production of *F. hallii* and *S. curtiseta* varied among landforms. As expected ANPP of *S. curtiseta* was greater than *F. hallii* on south aspects and level uplands because *S. curtiseta* is adapted to warmer and drier conditions than *F. hallii* (Ayyad and Dix 1964). Green standing crop, dead standing crop and ANPP were reduced longer after mowing *F. hallii* on the south aspect-concave slope, than when mowed on the other landforms. Growth after mowing can be modified by competition (Risser 1969). Since ANPP is an indicator of vigour (Coupland 1974), when ANPP is reduced the plant may not use resources as efficiently and those resources may be captured by other species whose production was not reduced after mowing. The fact that

F. hallii took longer to regain ANPP, green standing crop and dead standing crop on south aspects than on the other landforms suggests that this grass is more sensitive to mowing on the south aspect-concave slope compared to other landforms. Growing conditions are likely less favourable for *F. hallii* on the south aspect-concave slope compared to the other landforms.

While mowing did not appear to modify the microclimate of all landforms, mowing appeared to modify the microclimate on the south aspect-concave slope. Mowing *F. hallii* on the south aspect-concave slope reduced green standing crop and dead standing crop for up to 3 growing seasons. In contrast, green standing crop, dead standing crop and ANPP of *F. hallii* were reduced for 2 growing seasons on the other landforms. Therefore the hypothesis that ANPP of *F. hallii* is similar among months of mowing and among landforms is rejected.

With the exception of the level upland, *S. curtiseta* regained ANPP the growing season following mowing, suggesting the mechanisms for growth after defoliation are different from *F. hallii*. The ecological role of *S. curtiseta* in the plant community may influence ANPP. Slow growth on level uplands may be a function of competition. *Agropyron dasystachyum* was a co-dominant on level uplands. Competition among *S. curtiseta*, *A. dasystachyum* and other species on these landforms may have slowed growth of S. *curtiseta*. Rapid canopy reestablishment is an important characteristic of defoliation-tolerant plants (Caldwell et al. 1981, Richards and Caldwell 1985). With the exception of mowing in August, September or April on level uplands, *S. curtiseta* re-established ANPP the year following mowing. *Stipa curtiseta* thus appears more tolerant of mowing than *F. hallii* in the Northern Mixed Prairie.

Above ground net primary production of *F. hallii* was unaffected by mowing on the south aspect-convex slope. *Festuca hallii* was less frequent on the south aspect-convex slope; therefore the response of *F. hallii* to mowing may reflect the sporadic occurrence of the grass on this landform. *Festuca hallii* initiates leaf growth when soil temperatures are above 3 ºC (Redmann et al. 1993). South aspects typically warm sooner in the spring than do north aspects in the Northern Mixed Prairie (Ayyad and Dix 1964, Redmann 1975). With warmer conditions plants can initiate growth earlier on south aspects than on north aspects (Redmann 1975)allowing plants to photosynthesize and grow longer. A longer growing season on south aspects may have limited the growth of *F. hallii* (Weaver 1979). Drier conditions on south aspect-convex slopes than on other landforms on the study site might explain why *F. hallii* was least abundant on less on the south aspect-convex slope.

Green standing crop is produced and later transferred to dead standing crop. Therefore, green standing crop recovers before dead standing crop. The trends observed in dead standing crop for *F. hallii* and *S. curtiseta* among months of mowing were thus similar to those observed for green standing crop. With few exceptions, dead standing crop of *F. hallii* and *S. curtiseta* was generally reduced longer than green standing crop after mowing. The stage of plant growth at mowing and the environmental conditions after mowing control how long dead standing crop is reduced. Dead standing crop and litter play important roles in the dynamics of plant production in the Northern Mixed Prairie. Maintaining or restoring dead standing crop and litter is an important consideration when managing the Northern Mixed Prairie because the dead plant material and litter traps snow and reduces evaporation and environmental extremes

(Willms 1988b, Willms et al. 1996, Kowalenko and Romo 1998). Dead standing crop and litter decreases raindrop impact, runoff, soil erosion and soil surface evaporation (Tomanek 1969 from Naeth et al. 1991a) thereby moderating site hydrology (Naeth et al. 1991b) and contributing to the stability of plant production on the Northern Mixed Prairie.

Green standing crop, dead standing crop and ANPP of "other" plants were reduced by mowing for varying lengths of time among months of mowing and among landforms. The trends observed in the growth of "other" plants is similar to the trends observed in growth of *S. curtiseta* following mowing. The hypothesis that green standing crop and dead standing crop of "other" plants are similar among months of mowing is rejected.

6.0 MANAGEMENT RECOMMENDATIONS

Current recommendations (King et al. 1998) to defer grazing of *F. hallii* until after July are based on the assumption that plants are most sensitive to grazing while growing and least sensitive to grazing when they are not growing. Similarly, it is often recommended that grazing of *S. curtiseta* be deferred until later in the summer. Defoliation reduces the capacity for photosynthesis and plants need time before they can regain their ability to photosynthesize and recover green standing crop, dead standing crop and ANPP. Defoliation in May through August necessitates more time for green standing crop, dead standing crop and ANPP to recover to amounts similar to an unmowed control. In any case *S. curtiseta* and *F. hallii* can be grazed at any time of the year provided plants are allowed time to recover their ability to produce phytomass. The time needed to physiologically recover after grazing varies among species, landforms and aspects, and months of mowing.

Festuca hallii growth was reduced longer when mowed in May, June, July or August as compared to mowing in September, October, November or April. Willms (1991) concluded that Fescue grasslands are managed most efficiently with a single defoliation at the end of the growing season or in the fall or winter. Bailey and Anderson (1978), Willms and Fraser (1992), Brown (1995), Willms et al. (1996) and King et al. (1998) all suggested that defoliating *F. hallii* and a similar species, *Festuca scabrella* var. *campestris* (Rydb.), when dormant is generally less harmful than defoliating plants when they are growing. Regardless of when defoliated, *F. hallii* probably should not be grazed on an annual basis in the Mixed Grass Prairie and, depending on the month of defoliation, may require 2 or more consecutive growing seasons to recover production.

Festuca hallii needed at least 7 growing season months to recover its production potential after mowing in September, October, November or April and up to 11 growing season months after mowing in May, June, July or August.

Regardless of the month in which *S. curtiseta* is mowed, the grass should be rested in May and June or June and July to allow plants recover green standing crop and dead standing crop. Therefore, *S. curtiseta*-dominated rangeland must be rested 1 in every 3 growing seasons.

Plant communities in the study were composed of a mix of species, typical of the Mixed Grass Prairie in excellent ecological condition. Production of *F. hallii* was reduced the longest following mowing. Forage production of the plant communities on this landscape will be maintained by providing rest periods between defoliation events based on the number of growing season months for *F. hallii* to recover production.

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